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An evaluation of the Aviation Maintenance Climate Assessment Survey (MCAS), applies to the 3rd Marine Air Wing

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THESIS

AN EVALUATION OF THE AVIATION MAINTENANCE CLIMATE ASSESSMENT SURVEY (MCAS), APPLIED TO THE 3RD MARINE AIR WING

by

Christopher A. Harris

June 2000

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ABSTRACT *(maximum 200 words)*

Faced with aging aircraft and fewer acquisitions, Naval Aviation has redoubled its effort to preserve assets through preventative maintenance and reduction of aircraft mishaps. Eighty percent of all mishaps are due in part to human error, and approximately one out of five major mishaps are due to maintainer, line, or facility related factors. Among various efforts to systematically reduce mishaps is the use of the Maintenance Climate Assessment Survey (MCAS). This survey is designed to capture maintainer perceptions of safety. This thesis analyzes the results of 977 responses to MCAS given to the 3rd Marine Air Wing (MAW) maintenance personnel. In addition, it explores the MCAS's relationship with human errors present in 21 maintenance-related incidents (MRIs) using the Human Factors Analysis and Classification System - Maintenance Extension. This analysis finds statistically different responses among the squadrons of the 3rd MAW to the MCAS. These differences show the MCAS can detect variations between aviation units and associated Model of Organization Safety Effectiveness components. While no significant correlation between the nine adequately surveyed squadrons and their MRIs is found, a content analysis of the MCAS shows there is a relationship between the MRIs a squadron experiences and the items of the six MOSE components.

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AN EVALUATION OF THE AVIATION MAINTENANCE CLIMATE ASSESSMENT SURVEY (MCAS), APPLIED TO THE 3RD MARINE AIR WING

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Submitted in partial fulfillment of the
Requirements for the degree of

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ABSTRACT

Faced with aging aircraft and fewer acquisitions, Naval Aviation has redoubled its effort to preserve assets through preventative maintenance and reduction of aircraft mishaps. Eighty percent of all mishaps are due in part to human error, and approximately one out of five major mishaps are due to maintainer, line, or facility related factors. Among various efforts to systematically reduce mishaps is the use of the Maintenance Climate Assessment Survey (MCAS). This survey is designed to capture maintainer perceptions of safety. This thesis analyzes the results of 977 responses to MCAS given to the 3rd Marine Air Wing (MAW) maintenance personnel. In addition, it explores the MCAS's relationship with human errors present in 21 maintenance-related incidents (MRIs) using the Human Factors Analysis and Classification System - Maintenance Extension. This analysis finds statistically different responses among the squadrons of the 3rd MAW to the MCAS. These differences show the MCAS can detect variations between aviation units and associated Model of Organization Safety Effectiveness components. While no significant correlation between the nine adequately surveyed squadrons and their MRIs is found, a content analysis of the MCAS shows there is a relationship between the MRIs a squadron experiences and the items of the six MOSE components.

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EXECUTIVE SUMMARY

Faced with aging aircraft and fewer acquisitions, Naval Aviation has redoubled its efforts to preserve assets through preventative maintenance and reduction of aircraft mishaps. While dramatic strides were achieved in the last 50 years in reducing the Class A Flight Mishap (FM) rate, the presence of human error has remained relatively constant. In 1996, a Human Quality Management Board (HFQMB) was established to address human errors in FMs, and initially targeted aircrew error mishaps. The HFQMB achieved positive results, but as the last decade came to a close it was clear maintainer error would have to be targeted in order preserve aviation assets.

The Naval Safety Center and the School of Aviation Safety at the Naval Postgraduate School are addressing aircraft maintenance issues in order to achieve additional Class A FM reductions. Their efforts have generated two tools to assess maintainer error and trends and factors contributing to an incident, including the safety climate within which the organization operates. Schmidt, Schmorrow and Hardee (1998) develop the Human Factors Analysis Classification System - Maintenance Extension (HFACS-ME) taxonomy used to classify causal factors that contribute to maintenance-related incidents (MRIs). Schmorrow (1998), investigates all Naval Aviation class A, B and C MRIs and Teeters (1999) looks at all MRIs form the Fleet Logistic Support Wing. Both use HFACS-ME to analyze past mishap data building a Poisson model to predict future mishaps and through analysis of potential reductions associated with these error types forecast a decline in MRIs resulting in significant cost savings. Baker (1998), working with a model of safety effectiveness based on the concept of High Reliability Organizations, uses the existing Model of Safety Effectiveness and the Command Safety

Assessment (CSA) to develop a 35-item Maintenance Climate Assessment Survey (MCAS). Further work by Goodrum (1999), Oneto (1999), School of Aviation Safety, and AIRPAC refined the MCAS into a 43-question survey.

This study examines the MCAS ability to capture maintainer perceptions of maintenance operations and explores the relationship between MCAS and aircraft maintenance-related incidents (MRIs) using HFACS-ME. With the study of 977 maintainer surveys from the 3rd MAW, an effort to assess the maintenance safety climate within the wing is undertaken. Commander 3rd MAW, realizing the School of Aviation Safety was working on reducing MRIs, decided to seek assistance to access the reasons behind an increasing mishap rate in Fiscal Year 1999. The School of Aviation Safety provided various training and analysis including: CSA, MCAS, Ground Crew Coordination Training (GCT), Maintenance Operational Risk Management (MORM) awareness briefs, the HFACS-ME examination of Class A, B, C and Hazard Report (HAZREP) MRIs, and a package on Class A Helicopter and tactical aircraft (TACAIR) mishaps.

Through the use of Principal Component Analysis, this study validates the use of the MCAS in assessing a squadron's maintenance safety climate. Using Analysis of Variance (ANOVA) and Multiple Comparison testing, this study shows that there is a statistically significant difference between squadrons. Tukey's Multiple Comparison is used to aggregate units into above average, average and below average maintenance safety climate. Linear Regression is then preformed using mean MCAS responses as the predictor variable and the MRI rate as the response variable. While no significant correlation between the nine adequately surveyed squadrons and their MRIs is found, a

content analysis of the MCAS shows there is a correlation between the MRIs a squadron experiences and the items of the six MOSE components.

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DEDICATION

To my loving wife Katy for your patience, understanding and support during these last two years. To my daughters, Sydnye, Kelly and Tory who always understood why dad had to type on the computer when they were playing I express my love. To my parents and family who have supported me my entire life and continue to do so, once again I humbly say I am glad God put me in this family and I will never forget your support and love.

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I. INTRODUCTION

"Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity, or neglect" (Anonymous). Risk is inherent in Naval Aviation, however the success of Naval Aviation is based on a willingness to balance risk with the opportunity to take decisive actions necessary to succeed in battle (DON, 1997). However, squadron commanders have a fundamental responsibility to safeguard personnel and material resources, and to accept only minimal risk to accomplish an assigned mission (DON, 1997). There have been several major accidents in which organizational error plays a major role. One need only recall Three Mile Island (March 1979), the Space Shuttle Challenger (January 1986), and Chernobyl (April 1986) as examples of major accidents in which organizational error plays a significant role (Redmill & Rajan, 1997). Roberts (1990) observes that some organizations operate in a complex and hazardous environment, yet experience a very low accident rate. She terms these activities "high reliability organizations" or "HROs." Ciavarelli (1997) highlights research showing that HROs have certain key characteristics in common such as leadership style, management policies, procedures standardization, superior training, safety reward, adequacy of resources and staffing, and effective risk and hazard management. In a study of nuclear powered aircraft carriers, Roberts (1990) formally recognizes Naval Aviation as an HRO.

Despite Naval Aviation's success in reducing by 50 percent its Class A (those resulting in death, permanent disability, or loss of $1 million or more) Flight Mishap (FM) rate each successive decade between Fiscal Years (FY) 1950 and 1990, the proportion of aircraft losses attributable to human error has remained relatively constant

this decade (Ciavarelli & Figlock, 1997). Following the 1996 crash of a Navy F-14 in Nashville, Tennessee a Human Factors Quality Management Board (HFQMB) was formed with a goal to reduce Naval Aviation's Class A FM rate due to human error by 50 percent. The HFQMB initially focused on aircrew error, which was found to be a casual factor in 60 percent of all mishaps. However, it has increased its focus to encompass maintenance error that comprises approximately 15 – 20 percent of Class A mishaps.

A. BACKGROUND

The 3rd Marine Air Wing (MAW) has experienced a dramatic rise in their FY 1999 Class A Flight Mishap (FM) rate and, intrigued by the efforts of the HFQMB, requests from the School of Aviation Safety at the Naval Postgraduate school support in cutting their FM rate. The mission of the 3rd MAW is to provide combat-ready expeditionary aviation forces capable of short-notice worldwide deployment to Marine Air Ground Task Force (MAGTF) fleet and unified commander. The main aircraft of 3rd MAW are the AH-1W "Super Cobra", UH-1N "Huey", CH-53 "Super Stallion", CH-46E "Sea Knight", F/A-18D "Night Attack Hornet", F/A-18 "Hornet", AV-8B "Harrier" and the C-130T "Hercules". The 3rd MAW is composed of 25 combat squadrons, three training squadrons and four Marine Aviation Logistics Squadrons (MALS) divided among four Marine Air Groups (MAGs) located on three different Marine Corps Air Stations in Southern California. The MALS provide intermediate maintenance and aviation logistics support to squadrons within each respective MAG, whereas each squadron performs it's own organizational maintenance.

The function of the MAGs is to perform various related aviation tasks for the Marine Corps. The primary mission of MAG-11 (F/A-18, F/A-18D & C-130T) is to

provide air support to Marine Air Ground Task Force (MAGTF) commanders. MAG-13 (AV-8B) provides close-air support, conducts armed reconnaissance, and assumes limited air-defense roles. MAG-16 (CH-53 & CH-46E) performs its assigned mission of transportation and re-supply for Marine air and ground units. Finally, MAG-39 (AH-1W & UH-1N) provides utility helicopter support, close-in fire support, fire support coordination, aerial reconnaissance, observation and forward air control in aerial and ground escort operations during ship-to-shore movement and subsequent operations ashore.

The 3rd MAW, in dealing with is recent increased mishap rate, received constructive support from the School of Aviation Safety at the Naval Postgraduate School, in the form of training and analysis including: Command Safety Assessment (CSA), Maintenance Climate Assessment Survey (MCAS), Ground Crew Coordination Training (GCT), Maintenance Operational Risk Management (MORM) awareness briefs, the Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) examination of Class A, B, C and Hazard Report (HAZREP) maintenance-related incidents (MRIs), and a package on Class A Helicopter and tactical aircraft (TACAIR) mishaps. This support was implemented to evaluate their maintenance safety climate in an effort to understand the causes of the ground-based incidents.

B. PURPOSE

The intent of this study is three fold: 1) obtain 3rd MAW maintainer perception of maintenance operations safety with MCAS, 2) determine the if human error is a significant factor in 3rd MAW MRIs using HFACS-ME, and 3) evaluate the ability of the

MCAS to detect differences in squadron maintenance safety climate and how it is associated with their MRI histories.

C. PROBLEM STATEMENT

During FYs 1998 and 1999, 3rd MAW has suffered a dramatic increase in their mishap rate. The commander 3rd MAW, recognizing MRI's as a part of the problem, elected to have the School of Aviation Safety use the MCAS to capture maintainer perceptions of 3rd MAW maintenance operations and HFACS-ME for classifying human error that contributed to the 3rd MAWs MRIs. The 43-question version of the MCAS was administered to the 3rd Marine Air Wing (MAW) during the last half of 1999 in order to capture the maintainer's perception of their safety climate. In this thesis an analysis of 3rd MAWs MRIs from January 1998 to December 1999 is conducted to detect the human error present in the incidents as identified by HFACS – ME. The results are evaluated in an attempt to correlate these responses with the MRI data over the past 24 months. This research involves collection of survey results, generation of descriptive statistics of the survey, and employs statistical methods to address the following research questions.

1. Are there any noteworthy findings with respect to the MCAS? Are there any significant HFACS-ME trends observed for the MRIs?

2. Does the MCAS capture an overall attitude toward aviation maintenance safety and are all the questions in each component required to describe the majority of the variance of the component?

3. Does the MCAS detect maintenance safety climate differences between squadrons, type aircraft and Marine Air Groups and are these differences statistically significant as to cluster the different squadrons into groups?

4. Do squadrons that cluster below and above average as related to safety climate also have a higher and lower average number of mishaps respectively?

D. DEFINITIONS

This thesis uses the following definitions (DON, 1989):

Naval Aircraft. Refers to U.S. Navy, Naval Reserve, U.S. Marine Corps, and U.S. Marine Corps Reserve aircraft.

Maintenance-Related Incidents (MRIs)

Mishap. A Naval Aviation mishap is an unforeseen or unplanned event that directly involves naval aircraft, which result in $10,000 or greater cumulative damage to naval aircraft or personnel. The mishap is further divided into three classes based on the amount of damage to the aircraft, property and personnel injury. The following are the definitions of the three classes:

a. Class A. A mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability of a person occurs with direct involvement of naval aircraft.

b. Class B. A mishap in which the total cost of property damage (including all aircraft damage) is $200,000 or more but less than $1,000,000 and/or a permanent partial disability, and or the hospitalization of five or more personnel.

c. Class C. A mishap in which the total cost of property damage (including all aircraft damage) is $10,000 or more but less than $200,000 and/or injury results in one or more lost workdays.

Hazard Report (HAZREP) An incident in which the total cost of property damage (including all aircraft damage) is less the $10,000 and/or injury results in no lost workdays.

Incidence rate. The total number of Class A, B and C mishaps or HAZREPS per 100,000 flight hours.

Aircraft Ground Mishap (AGM). Those mishaps in which no intent for flight existed at the time of the mishap and $10,000 or greater aircraft damage or loss of an aircraft, and/or property damage occurred.

Flight Mishap (FM). Those mishaps in which there is $10,000 or greater aircraft damage or loss of aircraft with the existence of intent for flight for the aircraft existed at the time of the mishap.

Flight Related Mishap (FRM). Those mishaps in which there is no intent for flight at the time of the mishap and $10,000 or greater aircraft damage or loss of an aircraft, and/or property damage occurs.

Maintenance Climate Assessment Survey (MCAS). A 43-question survey used to gain insight into the maintenance community's perception concerning aviation mishaps within the Navy and Marine Corps.

Human Factors Accident Classification System – Maintenance Extension (HFACS-ME). A taxonomic system used to classify causal factors that contribute to maintenance related mishaps.

High Reliability Organization (HRO). An organization that operates in a hazardous environment, yet produces a very low rate of accidents and incidents by operating effectively, safely, and having the characteristics of leadership, sound management policies, procedure standardization, adequacy of resources and staffing, a defined system for risk management, and other factors. These traits can be divided into six components: 1) Process Auditing (PA) - an ongoing system to monitor hazards; 2) Reward System

(RS) - expected compensation or disciplinary action used to shape behavior; 3) Quality Assurance (QA) - policies and procedures for promoting quality performance; 4) Risk Management (RM) - organizational risk perception and mitigation; 5) Command and Control (CC) - policies and procedures to mitigate risks and 6) Communication / Functional Relationships (CF) - an environment where information is freely exchanged, quality assurance is seen as a positive influence and maintenance workers are shielded from external pressures to complete a task. This sixth trait encompasses a number of items specifically relating to maintenance that did not fit in the original traits of HROs.

E. SCOPE AND LIMITATIONS

This study uses the MCAS to survey the maintenance safety climate perceptions of the maintainers of the 3rd MAW and to validate the use of the MCAS as a tool to reliably asses this climate. A total of 17 California based USMC Active Duty Squadrons from the 3rd MAW participate in the survey. Only Naval Aviation maintenance personnel surveys are used in this analysis. Incomplete surveys or surveys with no variation in the responses are omitted.

The survey is administered at the various commands on site and participants are chosen from maintainers in the squadron in a non-random order. That is, only those maintainers that can participate in the survey at the time of administration are sent to participate. The differences in total surveys collected per squadron are due to the availability of maintainers and the commands willingness to participate in the survey. Also, during the timeframe of this study, all AV-8B "Harriers" are grounded for several weeks to assess the reliability of certain components of the airframe.

The Naval Aviation Safety Program mandates the investigation and reporting of all Class A, B and C incidents (OPNAV 3750.6Q, 1989). However, there are a number of difficulties in using the reports of these incidents. The information collected on incidents is not in HFACS format nor does it emphasize human factors. Further, fidelity is lost by transferring the incident investigation into the Safety Information Management System (SIMS) database. In addition, since OPNAV 3750.6Q only recommends but does not require the reporting of HAZEPS there number is underreported in the SIMS database. Finally, commands can influence the recorded or reported cost associated with a mishap thus lowering it from a mandatory reported Class C incident to a non-reported HAZREP.

Chapter II contains a literature review on investigative scope, high reliability organizations, human factors quality management board, maintenance climate assessment survey development, and human factors – maintenance extension development. In Chapter III the methodology used in this study is discussed. Chapter IV presents the results of this study. Lastly, Chapter V gives conclusions include findings and recommendations.

II. LITERATURE REVIEW

An in depth literature review is given in this chapter to give the reader an introduction to the relationship between organizational effects and safety and how two tools; the Maintenance Climate Assessment Survey (MCAS) and the Human Factors Analysis and Classification System (HFACS) can be used to understand this relationship. It will begin with an overview of high-reliability organizations. Next, a history of the Human Factors Quality Management Board (HFQMB) is discussed followed by MCAS and HFACS-Maintenance Extension (ME) development. The chapter finishes by summarizing this body of research and makes recommendations to tie HFQMB, MCAS and HFACS-ME into a three-pronged strategy to analyze risk and recommend a course of action to prevent a mishap from occurring in aviation organizations.

A. HIGH RELIABILTITY ORGANIZATIONS

One factor recognized as significantly contributing to a decrease in aircraft accidents is the technology advances in the design and maintenance of modern military aircraft (Roberts, 1990). However, Roberts (1990) finds this level of technical complexity makes military aircraft vulnerable to accidents or failures that cannot be predicted during the design process. In an effort to understand why certain organizations having a high level of complexity operating in a hazardous environment do not experience greater accidents as complexity increases, she observes that these organizations have certain factors in common. She calls these organizations "High Reliability Organizations" or "HROs".

Technology in general, aids in reducing mishaps, but the existing organizational research is inadequate to understand what organizational processes define HROs

(Roberts, 1990). Her research shows, that HROs have like leadership style, management policies, procedures standardization, superior training, and reward systems. These ideas and research by Libuser (1994) lead to the development of a Model of Organizational Safety Effectiveness (MOSE). The MOSE model organized HRO traits into the five categories of Process Auditing, Reward System, Quality Assurance, Risk Management and Command and Control (Libuser, 1994). The five MOSE components are summarized as follows:

1. Process Auditing – a system of ongoing checks to identify a hazardous condition and a process to take corrective actions.

2. Reward System – a system to recognize and reward safe behaviors, and to discourage unsafe behaviors.

3. Quality Assurance – Sets control procedures to monitor quality and correct deviations to referenced standards.

4. Risk Management – Systematic process to identify and manage risk.

5. Command & Control – an environment where information is freely exchanged, quality assurance is seen as a positive influence and maintenance workers are shielded from external pressures to complete a task.

B. HUMAN FACTORS QUALITY MANAGEMENT BOARD

In an attempt to address human error in Naval Aviation mishaps, a HFQMB was established in 1996. Its charter is to analyze human factor involvement in Naval Aviation mishaps and in Naval Aviation operations and develop interventions for them. Initially, the HFQMBs goal was to cut the mishap rate associated with human error in half (Nutwell & Sherman, 1997). The HFQMB used a "three-prong approach": 1) Mishap Data Analysis, 2) Benchmarking and 3) Climate Safety Assessment to identify human

error, uncover the best practice and find process improvements, and assess safety climate, respectively (See Figure 1).

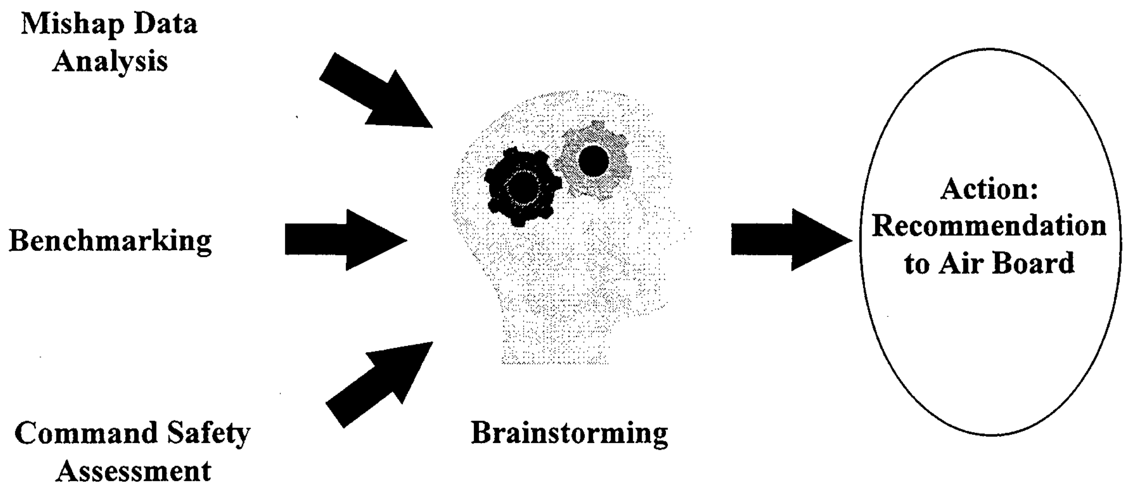

Figure 1. HFQMB Methodology (Schmidt, 1998)

Faced with aircrew error contributing to three out of five (Naval Safety Center, 1996) Class A Flight Mishaps (FMs) the HFQMB focused initially on them, and it consequently resulted in significant reductions in the Class A FM rate. These results coupled with emerging requirements to concentrate on aging aircraft related issues convinced the HFQMB to expand its scope to include human factors in maintenance-related mishaps (MRMs) using the same process (Schmidt, Schmorrow & Hardee, 1998).

C. MCAS DEVELOPMENT

Ciavarelli and Figlock (1997) develop a 67-item prototype "Command Safety Assessment" (CSA) for aircrew based on the descriptive MOSE components derived primarily from the works of Libuser (1994), Roberts (1990), Zohar (1980). Through the survey of 1,254 naval aviators and flight officers they are able to differentiate between squadrons having high scores for HRO components and those with low ones. This

research represents a first attempt to focus on key organizational issues in order to improve our understanding of the possible influence that a command may have in the chain of events leading to a maintenance-related aircraft mishap.

Where Ciavarelli and Figlock focus on organizational effects relating to aircrew safety issues, Baker (1998), Goodrum (1999), and Oneto (1999) focus on the organizational effects pertaining to maintainer safety issues. Baker (1998) uses the existing CSA and MOSE to develop a prototype MCAS. It consists of 15 demographic and 67 maintenance-related items. The demographic items include inquiries about rank, community, shift worked, total years of service, and total years of aviation maintenance experience. The maintenance-related items come from a candidate battery of over 200 items developed from the CSA, a Naval Safety Center (NAVSAFCEN) questionnaire, and noted questions from subject matter experts. Maintenance experts review this initial battery of questions and sort them according to the MOSE components. A number of items not fitting in the original five categories are placed in a sixth called Communication/Functional Relationship (CF) - an environment where information is freely exchanged, quality assurance is seen as a positive influence and maintenance workers are shielded from external pressures to complete a task. The questions are then organized according to their MOSE components.

Bakers' (1998) study includes 268 participants from three reserve squadrons that represented a spectrum of aviation communities. He tests the reliability and consistency of the prototype survey with a squadron from the Fleet Logistic Support (VR) Wing. With the survey shown to be content valid, Baker (1998) administers the prototype MCAS to two other groups of squadron maintenance personnel from the Maritime Patrol

and Reserve Helicopter Wing squadrons located at Moffett FAF and NAS North Island, respectively. Studying these Naval Air Reserve Force squadrons as well as input from the Naval Safety Center and the School of Aviation Safety his research results in a 35 item, six-component survey using a Likert type rating scale to assess safety in maintenance operations.

Goodrum (1999) works with VR Wing and surveys nearly 1000 maintainers from three different aircraft communities (C-9B, C-20, & C-130T). The results of the study concludes that the MCAS developed by Baker (1998) can be utilized as a tool for effectively capturing an aviation maintainer's perceptions of safety in maintenance operations. Through analysis of the MCAS responses a number of different areas related to the MOSE components are identified as raising concern within the different communities.

Oneto (1999), studying assorted aircraft communities within the Naval Air Reserve Force (NARF), also builds upon Bakers (1998) research, surveying 439 maintenance personnel of the NARF. Oneto's working independently from Goodrum also concludes that the MCAS is an effective tool for capturing an aviation maintainer's perceptions of safety in maintenance operations. However, in his study of NARF squadrons, Oneto fails to identify any single MOSE component responsible for controlling the outcome of the survey.

Goodrum and Oneto's combined studies: 1) validate the stability of the survey using Cluster Analysis by achieving similar conclusions through the use of two diametrically functioning algorithms and 2) validate the individual survey questions using principal component analysis. Further, both studies conclude by proposing a nearly

identical 40-item MCAS. Armed with this new revision, the Naval Safety Center, Naval Air Forces Pacific and School of Aviation Safety implemented revisions to come up with the current 43-item MCAS.

D. HFACS-ME DEVELOPMENT

The HFACS is a tool to analyze human errors contributing to Naval Aviation mishaps that was developed by Naval Aerospace Psychologists (Wiegman & Shappell, 1997) of the Naval Safety Center. (Schmidt et al, 1998). HFACS incorporates features of Bird's 'Domino Theory,' Edward's 'SHEL Model,' and Reason's 'Swiss Cheese Model.' (Schmidt, et al, 1998). Latent conditions and active failures are partitioned into one of three top-level categories. Unsafe Supervision and Operator Conditions are latent conditions while unsafe Acts of the Operator are active failures. Latent conditions are the result of decisions made by individuals who are not in direct control of the system (Zotov, 1996), and Active failures are those typically produced by "front-line" operators of the system (Reasons, 1998).

Drawing from HFACS a maintenance extension (ME) taxonomy was developed to classify causal factors that contribute to Maintenance Related Mishaps (MRMs). This addition to HFACS consists of four broad human error categories (see Figure 2): Supervisory Conditions (latent), Working Conditions (latent), Maintainer Conditions (latent), and Maintainer Acts (active). Under the umbrella of organizational climate are the latent factors, Supervisory, Maintainer, and Working Conditions that can impact a maintainer's performance and can contribute to an active failure, an unsafe maintainer act. These acts may directly lead to an incident (mishap or injury). The unsafe maintainer act may also become a latent maintenance condition, which the aircrew may

encounter while operating the aircraft. In addition, latent supervisory conditions may also lead directly to maintenance conditions.

Examples of how this taxonomy is applied for the first and second order error types are now given. Latent Supervisory Conditions that can contribute to an active failure include both unforeseen conditions and those conditions caused by the squadron supervisory environment. An example of unforeseen supervisory condition is an engine that falls off of a stand due to an unforeseen hazard of high seas state. An example of a squadron supervisory condition is a supervisor who does not ensure that maintenance personnel are wearing required personal protective gear.

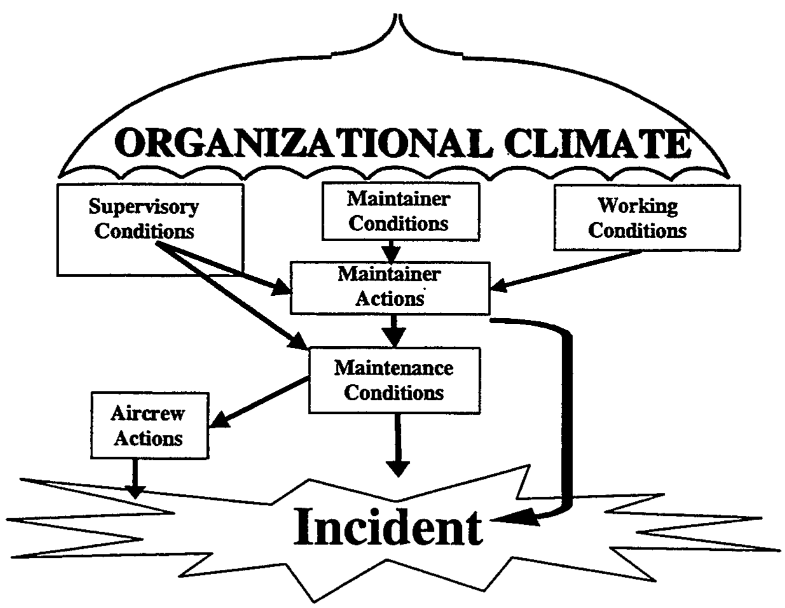

Figure 2. HFACS Maintenace Extension Diagram

Latent Maintainer Conditions that can contribute to an active failure include medical, crew coordination, and readiness. An example of a maintainer medical condition is a maintainer who has a marital problem and cannot focus on a maintenance

action. An example of maintainer crew coordination is a maintainer who performs a task, counter to standard procedures, because the maintainer is overly submissive to a superior. An example of maintainer readiness conditions is a maintainer who is working on an aircraft skipped the requisite on the job training evolution.

Latent Working Conditions that contribute to an active failure include environmental, equipment and workspace. An example of environmental working conditions is a maintainer who is working at night on the flightline does not see a tool he left behind. And example of equipment working conditions is a maintainer who is using a defective test set does not precheck it before troubleshooting. An example of workspace working conditions is a maintainer who is working in a hangar bay cannot properly position the maintenance stand.

Maintainer Acts are active failures, which directly or indirectly cause accidents, or lead to Latent Maintenance Condition, the include errors and violations. An example of errors in maintainer acts is a maintainer who is very familiar with a procedure might reverse steps in a sequence. An example of violations in maintainer acts is a maintainer who engages in practices, condoned by management, that bend the rules.

Table 1 shows the complete HFACS-ME categories having three orders: first, second and third that reflect a decomposition of the error types from macro to micro (Schmidt et al, 1998).

First Order	Second Order	Third Order
Supervisory Conditions	Unforeseen	Hazardous Operations Inadequate Documentation Inadequate Design
	Squadron	Inadequate Supervision Inappropriate Operations Failed to Correct Problem Supervisory Violations
Maintainer Conditions	Medical	Mental State Physical State Physical/Mental Limitation
	Crew Coordination	Communication Assertiveness Adaptability/Flexibility
	Readiness	Preparation/Training Qualification/Certification Violation
Working Conditions	Environment	Lighting/Light Exposure/Weather Environmental Hazards
	Equipment	Damaged Unavailable Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention Memory Rule/Knowledge
	Violation	Routine Infraction Exceptional

Table 1. HFACS Maintenance Extension Categories

Organizational climate can effect the three types of universal human activity that are common in hazardous environments: control under normal conditions, control under emergency conditions and maintenance-related activities. Reason (1997) defines maintenance-related to include unscheduled repairs, inspections, planned preventive

maintenance and calibration and testing. He further analyzes these activities and contends that it would be reasonable to expect that an activity scoring "high" in all three areas is the most likely to have a human performance problem. Of those universal human activities, Reason (1997) shows that these maintenance-related errors pose the largest human factors problem (see Table 2).

Activity	'Hands on'	Criticality	Frequency
Normal control	Low	Moderate	High
Emergency control	Moderate	High	Low
Maintenance-related	High	High	High

Table 2. The Relative Likelihood of Human Performance Problems in the Universal Human Activities

With this analysis complete Reason (1997) looks at which aspect of maintenance is most likely to be associated with "less-than-adequate" human performance. He concludes "that regardless of the domain, all maintenance-related activities require the removal of fastenings and the disassembly of components, followed by their reassembly and installation" the latter of which he identifies as the biggest problem (see Figure 3).

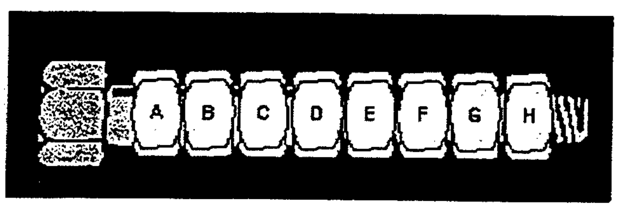

Figure 3. The bolt-and-nuts example

Reason (1999) argues that since there is only one way to remove the nuts, the chances of making an error are greatly reduced. However, in the case of installation there are over 40,000 ways in which the nuts can be reassembled in the wrong order. While this example may seem simple, it is also supported by available evidence from leading

aircraft manufactures that report that installation errors comprise over 70 percent of the contributing factors to maintenance-related events.

Reason (1997) further explains, errors committed by pilots, control room operators and other "sharp-end" personnel may be the last straw leading to an organizational mishap. However, it is the latent conditions created by maintenance-related mistakes that create the proper environment to start an accident in motion or make it impossible to recover when the error presents itself (Reason, 1997). By the same token, even though Reason (1997) paints a rather bleak picture with regard to maintenance-related errors, he states that they also offer the greatest opportunity for human factors improvements.

To identify aviation safety concerns related to maintenance, Schmorrow (1998) examines Naval Aviator maintenance mishaps using HFACS-ME. His research, based on a prior study by Schmidt, Schmorrow and Hardee (1998), develops a method to quantitatively determine the existence of significant patterns of human error involved in flight mishaps. Using HFACS-ME, Teeters (1999) considers MRMs, Hazardous Reports (HAZREPS) and Personal Injury Reports (PIPs). He shows that if reductions in causal factors can be achieved, then the numbers of incidents related to these causal factors should be reduced.

E. SUMMARY

In the face of diminishing budgets and reduced manning, during the past decade Naval Aviation has been faced with the problem of maintaining operational readiness in a "make do" environment (Schmorrow, 1998). HROs such as Naval Aviation with their ever-increasing reliance on advanced and complex systems need ways to identify and

reduce human errors. The HFQMB with its initial focus on aircrew error has expanded the scope of effort to include maintenance-related errors. Two tools used in this effort, are the MCAS and HFACS-ME. Developed through coordinated efforts between Air Forces Pacific, Naval Safety Center, and the School of Aviation Safety at the Naval Postgraduate School, it has been shown that these tools are effected in 1) effectively measuring and organization's safety climate and 2) classifying the errors present in those climates. It is hypothesized, that through the use of these devices one could assess a units risk and through analysis of the data recommend a preventive course of action to prevent a mishap from occurring Naval Aviation organizations.

III. METHODOLOGY

A. RESEARCH APPROACH

This study involves the analysis of data obtained from a 43 item Maintenance Climate Assessment Survey (MCAS), given to maintenance personal of the 3rd MAW. This survey is based on a model of HROs. The survey results are analyzed to determine the surveys validity and reliability. In addition, the survey results are then used to determine if they can be associated with observed maintenance-related incidents (MRIs). MRIs are classified in accordance with the Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) taxonomy to observe human error frequency and patterns.

B. DATA COLLECTION

1. Subjects

A total of 976 officer and enlisted personnel involved in aviation maintenance in the 3rd Marine Air Wing (MAW) participate in this study. The 3rd MAW units are located at Marine Corps Air Station Miramar, California, Camp Pendleton, California, and Marine Corps Air Station Yuma, Arizona (See Figure 4 for the 3rd MAW command structure).

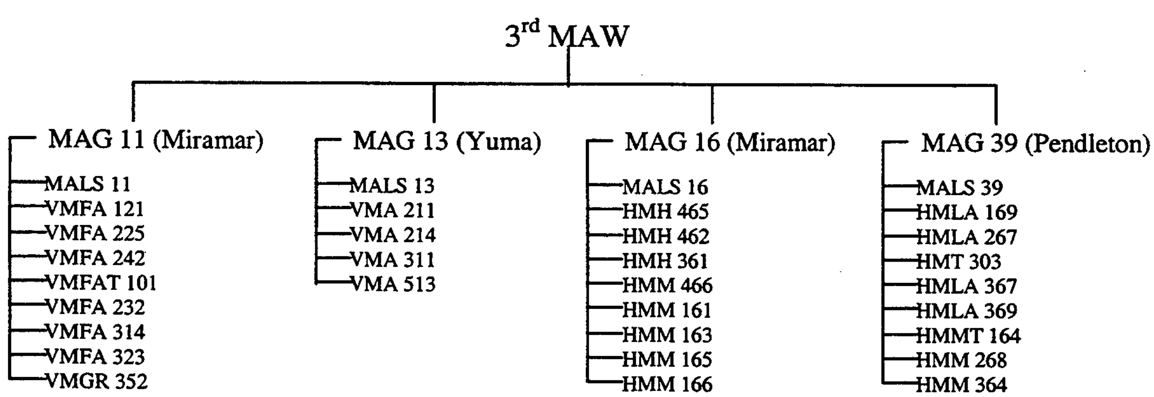

Figure 4. 3rd MAW Command Structure

Four mishaps and five hazard reports (HAZREPs) data from the 3rd MAW collected by the Naval Safety Center are used. The accidents in these reports occur between January 1998 to December 1999.

2. Instruments

a. MCAS

The MCAS a self-administered, group survey consisting of six demographic and 43 maintenance related items. The maintenance items of the MCAS are grouped into six categories or components: (process auditing, reward system, quality, risk management, command and control, and communication/functional relationships). The survey uses a five point Likert rating scale with verbal anchors as follows: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree.

b. HFACS-ME

HFACS-ME is used to classify casual factors that contribute to MRMs. This device uses a taxonomy that consists of four broad human error categories: Supervisory Conditions (latent), Working Conditions (latent), Maintainer Conditions (latent), and Maintainer Acts (active). This "first order effect" is further divided into second order and third order effects that decompose the error types from a macro to micro perspective. Since only first and second order casual factors Table 2 shows the reduced HFACS-ME categories. The mishap and HAZREP data is classified into first order causal factors that contribute to the MRMs using the Human Factors Accident Classification System – Maintenance Extension (HFACS-ME).

First Order	Second Order
Supervisory Conditions	Unforeseen Squadron
Maintainer Conditions	Medical Crew Coordination Readiness
Working Conditions	Environment Equipment Workspace
Maintainer Acts	Error Violation

Table 3. HFACS ME 1st & 2nd Order Categories

3. Procedure

a. MCAS

The survey is administered on site and in a group setting at the various participating squadrons of the 3rd MAW. Additionally, the survey is given in conjunction with a scheduled maintenance safety presentation on human factors issues in aviation. The squadrons are in various stages of training and operational tasking at the time of the survey. Differences in operational tasking account for much of the variability in the number of surveys collected from each squadron. For example, a squadron not in the area due to deployment during the time of the survey would not have been included in this study. The potential MCAS respondents are briefed on the survey and its purpose. Questions that arise pertaining to the survey are answered by the survey administer. All surveys are collected immediately upon completion to allow for maximum accountability.

b. Mishap / HAZREP Data

The Naval Safety Center (NAVSAFCEN) database was queried for all Marine Forces Pacific (MARFORPAC) incidents between Fiscal Year (FY) 1997 to February 2000.

C. DATA ANALYSIS

1. Data Tabulation

a. MCAS

Survey data sheets are scanned into a text file using a Scantron 8200 with Scanform version 3.21 software on an IMB compatible computer running Windows 3.1. The text file is converted into Microsoft Excel 2000 format. The spreadsheet consists of 976 rows of respondents and 51 columns containing demographic variables and survey responses. The first eight columns contain the demographic variables and the remaining 43 columns hold the subjects responses to questions 1 thru 43 of the survey. The demographic variables are: 1) aircraft community, 2) squadron number, 3) rank, 4) total years of aviation maintenance experience, 5) work center and 6) shift. All demographic information is then replaced by three variables indicating the squadron number, type aircraft and marine air group (MAG) from which the survey results are obtained. The 43 columns are further partitioned into six sets or components. The six components are: 1) Process Auditing (questions 1-6), 2) Reward Systems and Safety Climate (questions 7-14), 3) Quality Assurance (questions 15-20), 4) Risk Management (questions 21-29), 5) Command and Control (questions 30-37), and 6) Communications (questions 38-43). The responses in each column are scored as 1,2,3,4 or 5 corresponding to the Likert scale Strongly Disagree (E), Disagree (D), Neutral (C), Agree (B), Strongly Agree (A),

respectively. Question 21 is negative in wording compared to all other questions of the survey. Survey questionnaire items that have no response are left blank. Questionnaires that have blank entries for any question or item, or for which the same answer is given for all questions are eliminated. A complete list of removed data is available in the results section.

b. HFACS-ME

A request is made to Naval Safety Center to query the database in order to provide all maintenance-related mishap and HAZREP data for all Marine Forces Pacific commands between the years 1996 to February 2000. This query generates a text file from which is culled all mishap and HAZREP data for commands of the 3rd MAW from October 1997 to February 2000. These are then divided into Class A, B, C and HAZREP categories and are then evaluated into the HFACS-ME first and second order casual factors by the Naval Postgraduate School for Aviation Safety. Finally, simple counts are generated for the first and second order causal factors and these factors are then weighted to give an overall accident value for each squadron, type and MAG. These values are used to create a 3rd MAW maintenance-related error table.

2. Statistical Analysis

a. MCAS

Summary statistics are computed for each squadron, type aircraft and MAG in order to describe basic and general information about the question results. In particular, mean response for each question is computer by squadron, type aircraft and MAG. In addition, the questions within each of the six MOSE components are averaged for each respondent. These averages are then used as the independent variable in an

Analysis of Variance (ANOVA) to see if there is a difference in expected responses for different squadrons and for different MOSE components. It is noted that non-parametric analysis could also be done by replacing Likert scores with ranks before doing the ANOVA. However such non-parametric methods are a form of scoring and all methods are considered problematic (Kimeldorf, Sampson & Whitaker, 1992). Therefore, the very errors that a non-parametric approach might attempt to correct might in and of themselves introduce new unforeseen errors along with making the resulting analysis difficult to interpret to the population under study. Additionally, standard deviations are tabulated for the MOSE components and individual questions for each squadron, type aircraft and MAG. The S-Plus 2000 (Mathsoft, 1999) program is used for multivariate statistical analysis. Principal Component methodologies are used to validate the stability of the MCAS with a new population.

b. HFACS-ME

Summary statistics are developed for each squadron in order to describe basic and general information about the maintenance-related error. Simple linear regression is conducted with mean MCAS score as the independent variable and weighted MRI as the dependent variable. In addition, once complete an ad hoc procedure is conducted to see if the perceived safety climate predicted by the MCAS is related to an appropriate level of maintenance-related errors for those squadrons.

IV. RESULTS

A. MCAS DESCRIPTIVE STATISTICS

1. Sample

Maintenance Climate Assessment Surveys (MCAS) are collected from 977 military personnel serving in squadrons of the 3rd Marine Air Wing (MAW). Of these, 235 were in Marine Aviation Logistics Squadrons (MALS) and these surveys are not included in the study because these squadrons provide intermediate maintenance and do not have aircraft or aircrew directly assigned to them. Additionally, 61 surveys are removed from this remaining group either because of missing values (55) or the same response to all 43 questions (six). The remaining 681 surveys will be addressed in the MCAS Results section of this thesis.

2. Analysis of Removed Surveys

An effort is taken to determine if removing the 61 surveys with missing values or constant response introduces bias in the Principal Component Analysis. Of the 55 surveys removed due to missing values, there are a total of 74 questions left blank. Table 4 shows the questions associated with a missing value and the number of times that the particular question is not answered. Of note, are questions 17, 29, 36, 42 and 43, they are: 17) "QARs/CDIs sign-off after required actions are complete and are not pressured by supervisors to sign-off," 29) "Based upon my command's current assets/manning it is not over-committed," 36) "All maintenance evolutions are properly briefed, supervised, and staffed by qualified personnel," 42) "Maintenance Control troubleshoots/resolves gripes before flight," and 43) "Maintainers are briefed on potential hazards associated with maintenance activities. These questions account for approximately 64 percent of the

missing values, with question 43 accounting for nearly 33 percent. In addition, 11 out of the 12 people who fail to answer question 42 also fail to answer question 43. According to Reasons (1998) this effect is observed for questions at the end of surveys producing what he calls "end effect." Because questions 42, and 43 are the only questions on the last page of the survey this effect is amplified.

#	Questions
0	3,5,9,10,11,14,15,16,18,20,24,26,32,33,37,40
1	1,2,4,6,8,12,13,19,21,22,27,28,30,31,34,35,39
2	7,23,25,38,41
3	17
4	29,36
12	42
24	43

Table 4. Number Response Missing by Question

To see if the 61 surveys differ from the other 681 surveys, the demographic variables of rank and squadron are compared. Table 5 lists the frequency and percentages of the surveys removed by rank. In Figure 5, these are compared to the surveys retained in the analysis. This figure shows that those surveys removed are representative of the remaining surveys used for the Principal Component Analysis and no bias should be introduced by their removal.

Blank		E1-3		E4-5		E6-9		Officer	
#	%	#	%	#	%	#	%	#	%
1	1.7%	32	53.3%	21	35.0%	6	10.0%	0	0.0%

Table 5. Percentage and Count of Removed Surveys by Participant Rank Response

Table 6 shows the frequency of surveys removed from a particular squadron. The tables shows a range of removed surveys between two percent for squadron B and 17 percent for squadron F with an overall average of 10 percent surveys that have either a missing value or the same response for all questions.

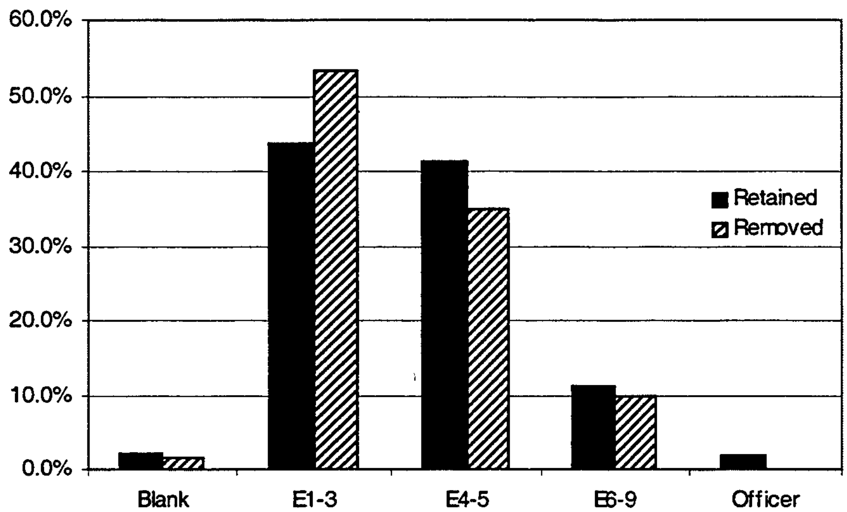

Figure 5. Comparison of Retained and Removed Surveys by Rank

A	B	C	E	F	G	H	I	J	K	L	M	O	P	Average
11%	2%	6%	13%	17%	12%	11%	11%	11%	9%	16%	7%	4%	9%	10%

Table 6. Frequency by Squadrons of Surveys Removed

3. Demographics

The number of survey participants are given by rank and squadron in Table 7. In this table, participant squadrons and Marine Air Groups (MAGs) are randomly assigned letters in place of the squadron identifier. Approximately 84.9 percent of those participating in the MCAS are enlisted maintainers serving in the ranks of E1 - E5. This percentage agrees with the 79.2% observed by Goodrum (1999) in his study of squadrons of the Fleet Logistics Support Wing and the 81% observed by Oneto (1999) in his study

of aircraft communities within the Naval Air Reserve Force. Similar proportions for all squadrons are observed for the MCAS participants except those units that contribute a low number of surveys as shown in Figure 6. Histograms of other descriptive demographic variables such as: 1) Total Years Maintenance Experience, 2) Work Center, and 3) Shift are given in Appendix (C).

	Blank		E1-3		E4-5		E6-9		Officer		
Squadron	#	%	#	%	#	%	#	%	#	%	**Total**
A	2	3.2%	23	37.1%	28	45.2%	9	14.5%	0	0.0%	62
B	0	0.0%	22	52.4%	17	40.5%	2	4.8%	1	2.4%	42
C	1	1.4%	30	43.5%	34	49.3%	3	4.3%	1	1.4%	69
D	0	0.0%	9	42.9%	11	52.4%	1	4.8%	0	0.0%	21
E	0	0.0%	4	50.0%	1	12.5%	3	37.5%	0	0.0%	8
F	4	6.2%	39	60.0%	20	30.8%	2	3.1%	0	0.0%	65
G	1	2.0%	16	32.0%	22	44.0%	8	16.0%	3	6.0%	50
H	0	0.0%	9	47.4%	5	26.3%	3	15.8%	2	10.5%	19
I	0	0.0%	35	48.6%	28	38.9%	9	12.5%	0	0.0%	72
J	0	0.0%	4	44.4%	4	44.4%	1	11.1%	0	0.0%	9
K	0	0.0%	9	81.8%	2	18.2%	0	0.0%	0	0.0%	11
L	0	0.0%	14	37.8%	19	51.4%	3	8.1%	1	2.7%	37
M	3	3.4%	44	50.0%	30	34.1%	9	10.2%	2	2.3%	88
N	0	0.0%	0	0.0%	1	11.1%	7	77.8%	1	11.1%	9
O	3	5.6%	15	27.8%	29	53.7%	6	11.1%	1	1.9%	54
P	1	1.8%	22	38.6%	29	50.9%	5	8.8%	0	0.0%	57
Q	0	0.0%	2	25.0%	1	12.5%	5	62.5%	0	0.0%	8
Total	**15**	**2.2%**	**297**	**43.6%**	**281**	**41.3%**	**76**	**11.2%**	**12**	**1.8%**	**681**

Table 7. Number and Percentages of Respondents by Rank for each Squadron

Figure 6. Percentage of MCAS Respondents' with Rank E1-E5 for each Squadron

4. MCAS MOSE Component Statistics

Table 8 displays the six MOSE categories and respective MCAS questions that comprise each component. Table 9 displays the mean response by component and squadrons of the 3rd MAW. The 3rd MAW question averages by squadron and the MOSE component statistics for the MAGS and type aircraft can be found in Appendices C and D respectively.

MOSE Category	Questions
Process Auditing (PA)	1, 2, 3, 4, 5, 6
Reward System & Safety Climate (RS)	7, 8, 9, 10, 11, 12, 13, 14
Quality Assurance (QA)	15, 16, 17, 18, 19, 20
Risk Management (RM)	21, 22, 23, 24, 25, 26, 27, 28, 29
Command & Control (CC)	30, 31, 32, 33, 34, 35, 36, 37
Communication / Functional Relationships	38, 39, 40, 41, 42, 43

Table 8. MOSE Categories and Questions

Sqdrn	Process Auditing	Reward System	Quality Assurance	Risk Management	Command & Control	Comms/ Func Rel	Sqdrn Mean
A	3.75	3.41	3.63	3.12	3.50	3.43	**3.47**
B	4.07	3.53	3.94	3.47	3.85	3.66	**3.75**
C	4.00	3.34	3.56	3.30	3.40	3.37	**3.49**
D	3.71	3.51	3.66	3.33	3.49	3.48	**3.53**
E	3.60	3.69	3.73	3.32	3.59	3.52	**3.58**
F	4.02	3.67	3.60	3.65	3.68	3.55	**3.69**
G	3.79	3.37	3.42	2.98	3.33	3.21	**3.35**
H	3.89	3.47	3.73	3.61	3.71	3.71	**3.69**
I	3.98	3.39	3.52	3.28	3.51	3.53	**3.53**
J	3.96	3.74	3.89	3.63	3.92	3.87	**3.83**
K	3.53	3.18	3.36	3.13	3.32	3.17	**3.28**
L	4.02	3.74	3.99	3.56	3.83	3.92	**3.84**
M	3.61	3.25	3.37	2.99	3.17	3.19	**3.26**
N	3.70	3.51	3.59	3.17	3.44	3.44	**3.48**
O	3.58	3.21	3.32	2.82	3.18	3.20	**3.22**
P	3.74	3.28	3.66	3.20	3.45	3.63	**3.49**
Q	3.96	3.88	3.88	3.72	3.80	3.75	**3.83**
Component Mean	**3.82**	**3.48**	**3.61**	**3.31**	**3.54**	**3.51**	**3.55**

Table 9. Mean MCAS Response by Component and Squadron of 3rd MAW

B. MCAS PRINCIPAL COMPONENT ANALYSIS

Principal Component Analysis (Hamilton, 1992) is performed on the survey data to test whether the factors that make up the survey account equally for most of the variability of the data. Using S-Plus 4.5, the command "princomp (MAW, cor = F)" is used to produce the results of the principal component analysis. The Principal Component is defined as the 681 by 43 matrix of survey responses (one row per survey and one column per question). In addition, the analysis is based on the covariance matrix rather than the correlation matrix. The covariance matrix is used since all questions are on a common scale. Principal Component Analysis is often used to reduce the number of explanatory variables (questions), however it is being used here to revalidate the survey by showing no reduction is required. A scree-plot is used to display the output of the principal component analysis (see Figure 7).

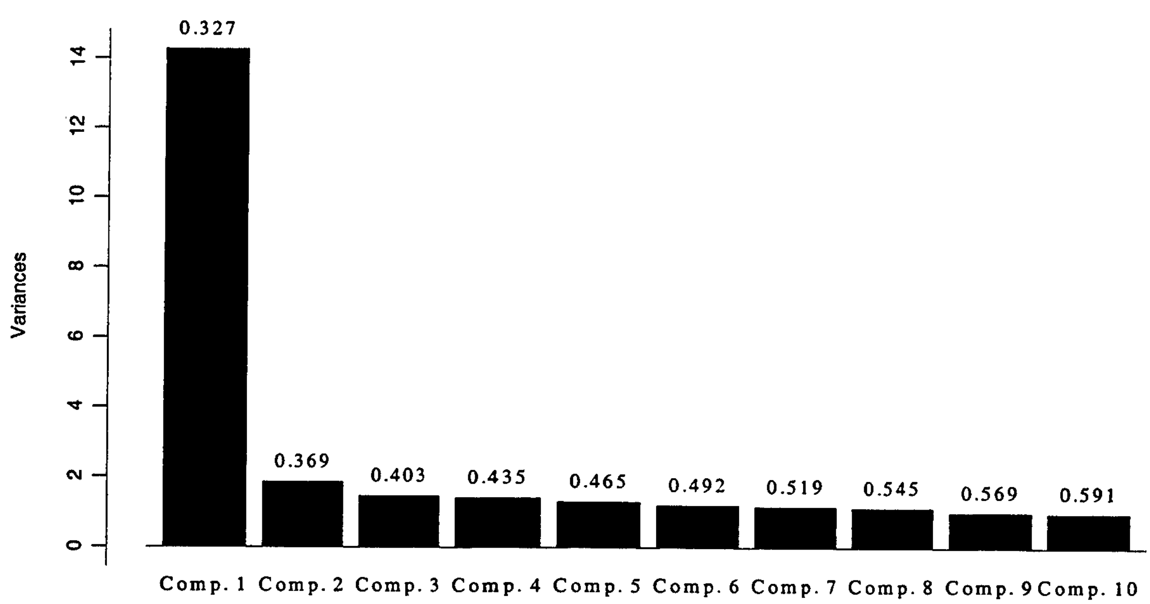

Figure 7. Principal Component Scree-Plot.

In this figure, the variance contributed by each component is plotted and the cumulative variance given. Only the first 10 of 43 components of the Principal Component Analysis are displayed. The principal component loadings are the coefficients of the principal components transformations. Observe that the first component, which is the maximum variance of the data, explains 32.7 percent of the total variance of the survey. As shown in Appendix E all questions load equally across the first component. Additionally, with a large difference between the 1st and 2nd component and a gradual decrease thereafter, this suggests that the survey is dominated by the first component and that linear combinations of the questions combine for the remaining variance. This analysis has one important implication, the questions in the survey are contributing equally to the overall assessment of maintenance climate, and the individual questions and their interactions are required to capture this climate.

C. MCAS MOSE COMPONENT ANALYSIS

Only squadrons with at least 25 surveys are used to do further explanatory analysis, Analysis Of Variance (ANOVA) and Multiple Comparison Analysis (MANOVA) on the MOSE components. Since most squadrons have a maintainer census between 90 and 150, with an average of 120, it is deemed necessary to capture at least 20 percent of the maintainers' perceptions in order to draw any meaningful conclusions from the survey. The data set is reduced by 85 surveys to 596 by eliminating squadrons D, E, H, J, K, N and Q. This reduction eliminates the ability to compare differences between MAGs and type aircraft. Table 10 shows the remaining squadrons and their MOSE component statistics.

Sqdrn	Process Auditing	Reward System	Quality Assurance	Risk Management	Command & Control	Comms/ Func Rel	Sqdrn Mean
A	3.75	3.41	3.63	3.12	3.50	3.43	**3.47**
B	4.07	3.53	3.94	3.47	3.85	3.66	**3.75**
C	4.00	3.34	3.56	3.30	3.40	3.37	**3.50**
F	4.02	3.67	3.60	3.65	3.68	3.55	**3.70**
G	3.79	3.37	3.42	2.98	3.33	3.21	**3.35**
I	3.98	3.39	3.52	3.28	3.51	3.53	**3.54**
L	4.02	3.74	3.99	3.56	3.83	3.92	**3.84**
M	3.61	3.25	3.37	2.99	3.17	3.19	**3.26**
O	3.58	3.21	3.32	2.82	3.18	3.20	**3.22**
P	3.74	3.28	3.66	3.20	3.45	3.63	**3.49**
Component Mean	**3.86**	**3.42**	**3.60**	**3.24**	**3.49**	**3.47**	**3.51**

Table 10. Mean Survey Response by Component and Squadron for Squadrons with at least 25 Surveys

Figures 8 and 9 are bar charts showing the MOSE mean responses of the components and MCAS mean responses for the squadrons, respectively. The average Likert scale response (1 = "Strongly Disagree, 2 = "Disagree", 3 = "Neutral", 4. "Agree," 5 = "Strongly Agree") for both the MOSE components and the squadrons was 3.51. Of note is the mean for Risk Management (RM) is 3.24 with a low of 2.82 (O) and a high of 3.65 (F). The highest scored component is Process Auditing (PA) with a mean of 3.86 and a high of 4.07 (B) and low of 3.58 (O). For the squadrons notice that G, M and O are well below the mean while the high for all is 3.84 (L) and the low is 3.22 (O).

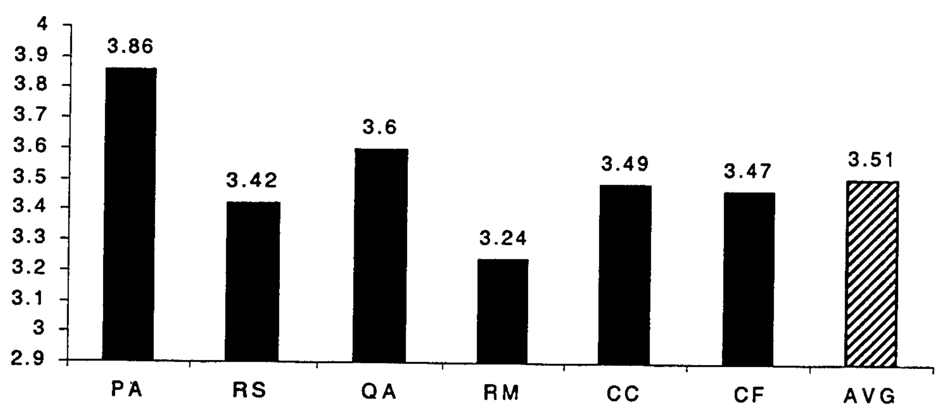

Figure 8. MOSE Component Means with Average

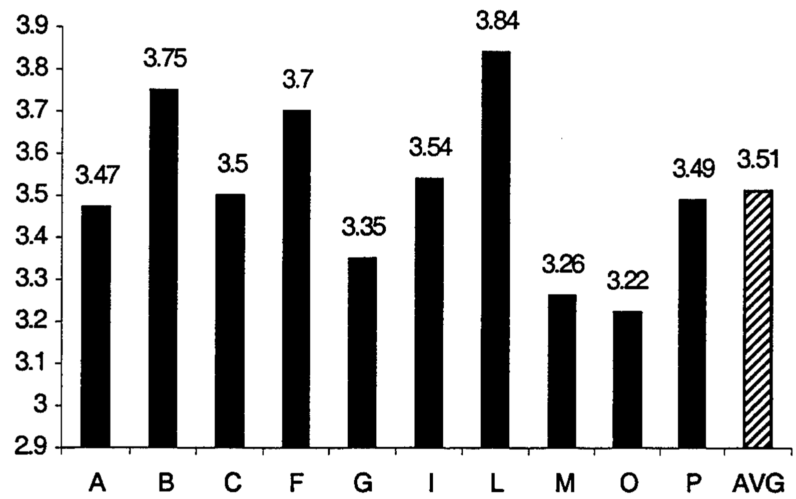

Figure 9. Squadron MCAS Means with Average

1. Analysis of Variance

A two-factor ANOVA is conducted to determine if either the squadron or the MOSE component show any effect on the mean survey response. Let I represent the levels of the first factor (squadrons) and J represent the levels of the second factor (MOSE components) then in this data set I=10 (the ten squadrons) and J=6 (the six MOSE components), and there are $I*J$=60 possible cross classifications that make up the levels of the two factors. The dependent variable is the mean question response given in Table 10.

Appendix F has a detailed listing of the S-PLUS code and associated output in the ANOVA analysis on the data in Table 10. The results of the analysis on the two factors with average as the response is displayed on the next page in Table 11.

	df	Sum of Sq	Mean Sq	F	Pf-value
Squad	9	2.27	0.252	26.7	3.22×10^{-15}
Comp	5	2.13	0.426	45.1	2.20×10^{-15}
Residuals	45	0.43	0.000		

Table 11. Analysis of Variance on Squadron and MOSE Factors

The p-values for the null hypothesis that there is no squadron effect and there is no component effect are less than 10^{-14}. Thus there is strong evidence that at least one squadron has a statistically different mean score, and there is strong evidence that at least one of the MOSE components do not yield the same mean responses.

2. Multiple ANOVA Comparisons

A multiple comparison test using Tukey's Procedure (or "T" method) is conducted to determine which squadrons are different from one another. Utilizing the Studentized Range probability distribution, simultaneous confidence intervals for all pairwise comparisons were computed at a selected level of significance. In this case, the pairwise comparing of the means of all six MOSE components results in fifteen comparisons. The resulting confidence intervals are intervals for the values of all pairs of differences between true treatment means. Each interval that doesn't include the value of zero yields the conclusion that the treatment means differ significantly (Devore, 1995).

Appendix F has a detailed listing of the S-PLUS code and associated output for Tukey's procedure. Figure 10 is the boxplot of mean responses for the 10 squadrons. Having the squadron means of 3.22 (O), 3.26 (M), 3.35 (G), 3.47 (A), 3.49 (P), 3.49 (C), 3.54, (I), 3.70 (F), 3.75 (B), and 3.84 (L) arranged in increasing order, the graphical display of the confidence intervals (Figure 11) is used to obtain those pairings that

contain a value of zero. The results of this comparison is summarized graphically in Figure 12. Any squadrons not underscored by the same line, are statistically different from each other at a five percent level of significance. Figure 12 shows that O and M are different from all other squadrons except G. Squadrons A, P and C are different from O, M and F, B, and L. Finally, squadrons B and L are different from all other squadrons except F. Since G and F form the bridge between the three groups they are considered boundary squadrons having characteristics of two groups.

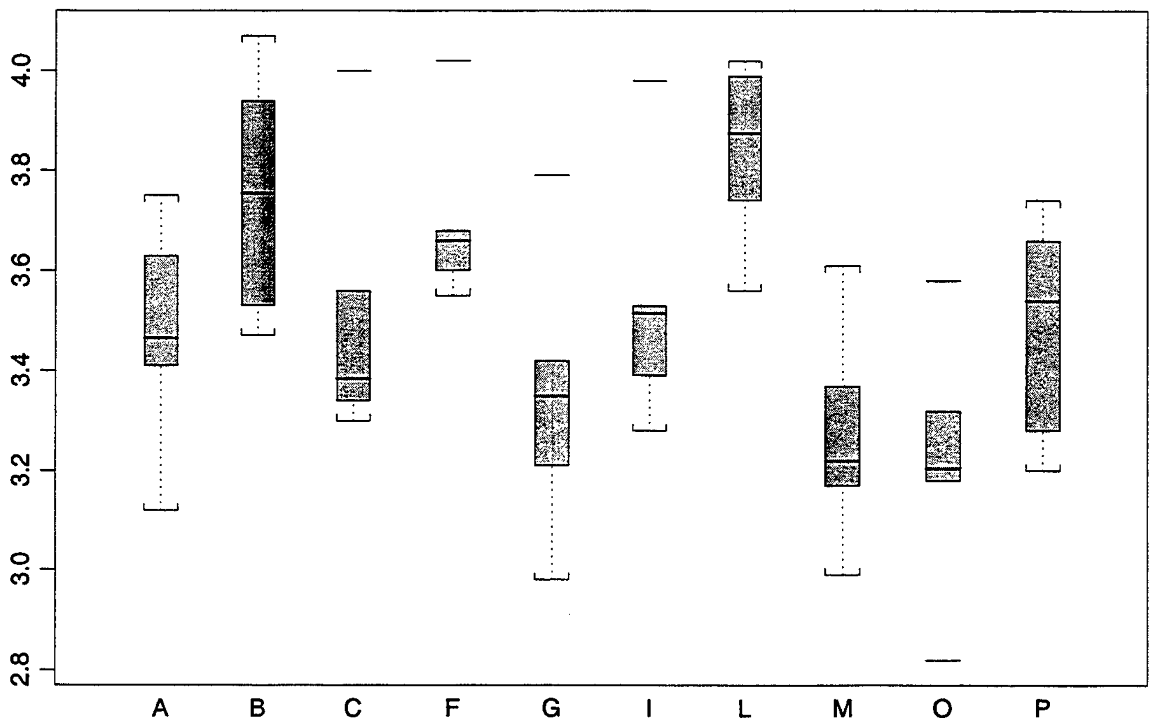

Figure 10. Boxplots of Squadrons

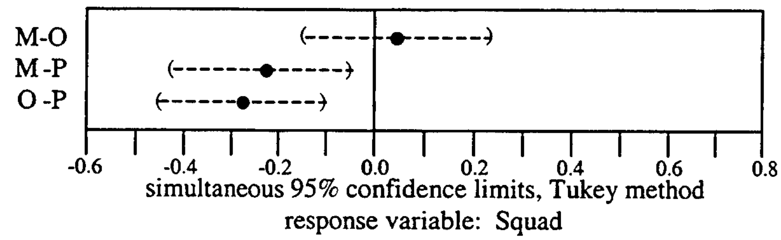

Figure 11. Tukey's Pairwise Comparison of Squadrons

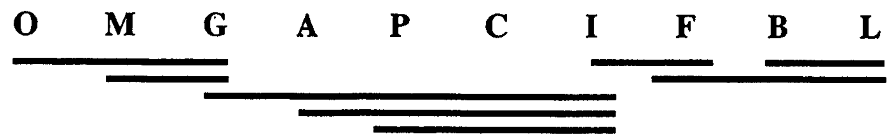

Figure 12. Identifying Statistically Different Squadrons

Finally, a multiple comparison analysis is conducted on the MOSE component factor in the same manner as above. Again, having the MOSE component means of 3.24 (RM), 3.42 (RS), 3.47 (CF), 3.49 (CC), 3.60 (QA), and 3.86 (PA) arranged in increasing order, the graphical display of the confidence intervals (Figure 13) is used to obtain those pairing that contain a value of zero. Those squadrons are then underlined as shown in Figure 14. Figure 14 shows that RM and PA are found to be different from all other components. QA is found to be different from all components except CC.

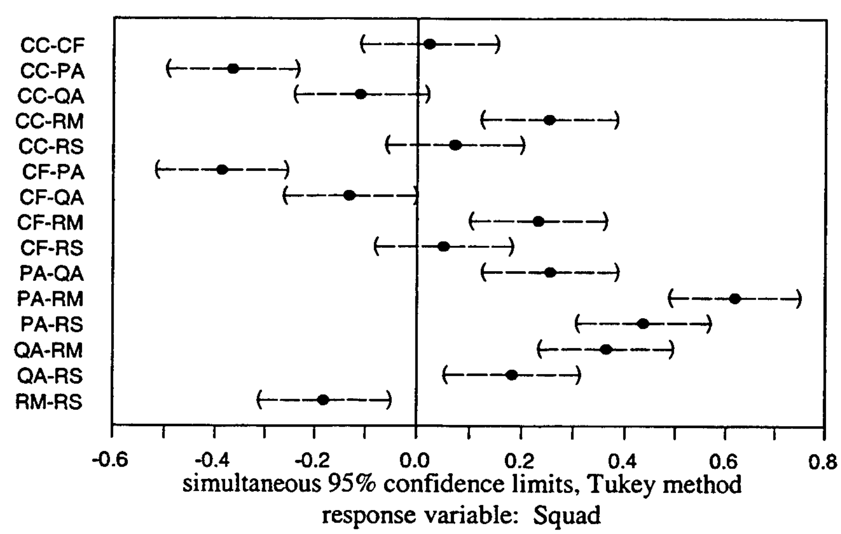

Figure 13. Tukey's Pairwise Comparison of MOSE Components

RM RS CF CC QA PA

Figure 14. Identifying Statistically Different MOSE Components

D. HFACS-ME DESCRIPTIVE STATISTICS

Between calendar years 1998 – 1999 the 3rd MAW experienced two class A, three class B, four class C Maintenance Related Incidents (MRIs) 13 HAZREPS. Table 12 lists the MRMs with the associated cost of the mishap or HAZREP. During this time frame, squadrons D, L, M, P and Q reported no MRMs or HAZREPS.

	Class A	Class B	Class C	HAZREP
A				$10,000
B			$162,282	
C	$11,783,499			
E		$227,350 $360,515	$195,730	$10,000 $10,000
F	$24,397,330			$10,000 $10,000
G				$10,000
H				$10,000
I				$10,000 $10,000
J				$10,000
K			$116,751 $77,005	$10,000 $10,000
N				$10,000
O		$120,487		

Table 12. Class A, B and C MRMs and HAZREPS for the 3rd MAW between Jan 1998 – Dec 1999

Using HFACS-ME to identify the casual factors in the MRIs and HAZREPS the total first and second order casual factors for each squadron reporting an incident are

counted and are presented in Table 13. If there is no second order casual factor observed that column is removed.

	MA		MC	SC		WC
	Error	**Violation**	**Crew Coord**	**Unforeseen**	**Sqdrn**	**Equipment**
A	1				1	
B	1	1	1		2	
C	2				1	
D						
E	5	1		4	1	1
F	2	2		1		
G	1					
I	1	1		1	2	
J	1					1
K	4	1			3	
N	1					
O	1	1		3	1	

Table 13. HFACS-ME 1st and 2nd Order Casual Factors for MRIs and HAZREPS of the 3rd MAW between Jan 1998 – Dec 1999

E. HFACS-ME / MCAS CORRELATION ANALYSIS

Finally, an effort is undertaken to identify relationships between the average MCAS score for a squadron and their MRIs and HAZREPS. This is accomplished by first combining all MRIs and HAZREPS for each squadron, and then dividing by the total flight hours for the past two years, giving an incident rate per flight hour. The summary of this computation along with mean MCAS response for each squadron is given in Table 14. A simple linear regression of MCAS mean response versus incident rate from Table 14 is performed. Note that, only those squadrons who completed 25 or more surveys are included. Figure 15 plots the linear regression with mean MCAS as the predictor variable and incident rate per flight hour as the response variable. Squadron F can be observed as an influential point greatly affecting the slope coefficient in the regression. Figure 16 gives the same linear regression with squadron F removed. Appendix G

contains the detailed results of both regressions. For the model containing F the estimated slope coefficient is 32.8 with an associated t-value of .672. For the model without F the estimated slope coefficient is –8.71 with an associated t value of –.395; neither gives slopes that are statistically different from zero. Thus, the results are inconclusive. There is not enough evidence to say that there is a relationship (either positive or negative) between mean MCAS response and incident rate. Similar results are obtained when incidents are weighted according to cost.

	# Incidents	Flight Hours (FH)	Incident / FH	Mean MCAS
A	1	7257.2	13.8	3.47
B	1	12076.6	8.3	3.75
C	1	6403.9	15.6	3.49
F	3	3128.9	95.9	3.69
G	1	6209.3	16.1	3.35
I	2	5246.5	38.1	3.53
L	0	2378.2	0.0	3.84
M	0	3052.9	0.0	3.26
O	1	6402	15.6	3.22
P	0	5783.2	0.0	3.49

Table 14. 3rd MAW Incident, Flight Hour, Incident Rate and Mean MCAS data from Jan 1998 – Dec 1999

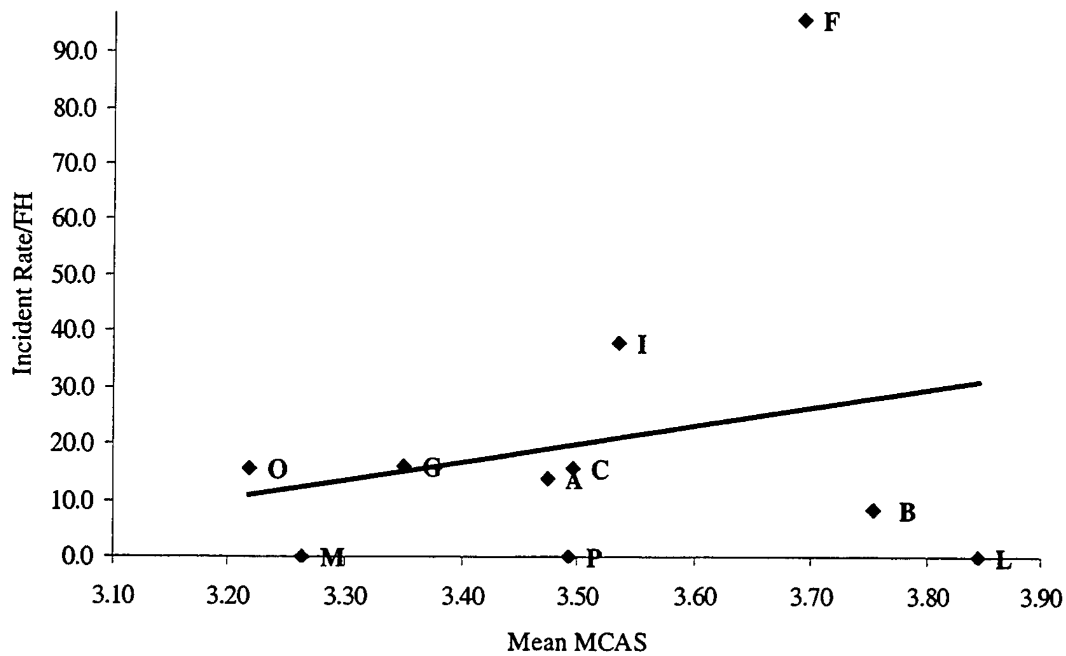

Figure 15. Simple Linear Regression with Mean MCAS as Predictor and Incident Rate/FH as Response

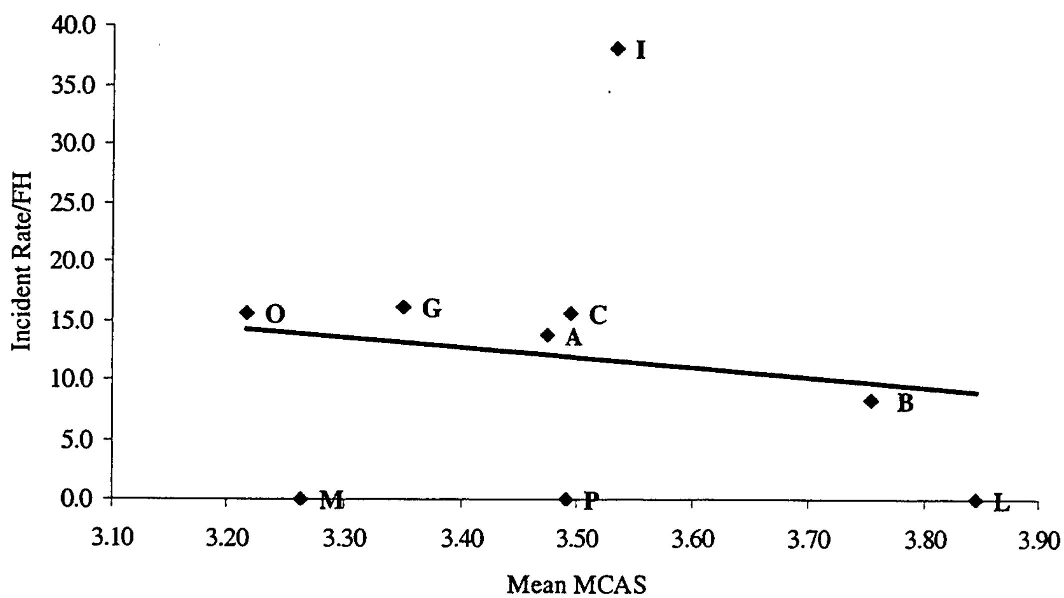

Figure 16. Simple Linear Regression with Mean MCAS as Predictor and Incident Rate/FH as Response minus F

Table 15 summarizes an ad hoc analysis done by the School of Aviation Safety at the Naval Postgraduate School on the 10 MRIs of the 3rd MAW and the MCAS MOSE components. In this analysis, two people with expertise in general aviation and aviation safety review 10 MRIs. In Table 15, an "X" in the cell indicates that at least one question in a particular component addresses the casual factors associated with the incident and that both persons evaluating the MRI at the School of Aviation Safety at the Naval Postgraduate School agree that the incident has that MOSE component associated with at least one of the causal factors in the incident. For example, the MOSE component, PA, has at least one question that addresses a casual factor in incidents "1", "2", "4", and "6" and incident "1" has a PA and CF MOSE component in the causal factors.

This table indicates that based on expert judgement, there appears to be a relationship between the MOSE components of the MCAS and the MRIs. Every incident has at least one causal factor associated with a MOSE component. Of note is the high occurrence of the MOSE component QA showing up in eight out of ten incidents. Likewise, the MOSE component RS has a low occurrence showing up in only one out of ten incidents.

		INCIDENTS									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
MOSE COMPONENTS	**PA**	X	X		X		X				
	RS			X							
	QA		X	X	X	X	X	X		X	X
	RM					X					X
	CC			X	X				X		X
	CF	X			X						

Table 15. 3rd MAW Incident Factors Captured by MCAS MOSE Components

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V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

A. SUMMARY

Squadron commanders have a fundamental responsibility to safeguard personnel and material resources while at the same time minimizing risk while accomplishing assigned missions. Dramatic strides in reducing the Class A Flight Mishap (FM) rate have occurred and only recently have these reductions begun to level off forcing Naval Aviation to look at alternate ways to continue the reduction. Recognizing that one in five Naval Aviation Class A FMs has maintenance-related casual factors a recent effort has begun to address aircraft maintenance issues in order to continue the Class A FM reductions. Additionally major and minor mishaps have come under review and for this study were called maintenance-related incidences (MRIs).

The primary focus of this study was to analyze the Maintenance Climate Assessment Survey (MCAS) and its ability to capture maintainer perceptions on 3rd Marine Air Wing (MAW) maintenance operations. Of secondary interest, was the application of the Human Factors Accident Classification System – Maintenance Extension (HFACS-ME) to the 3rd MAW to explore their human errors and to assess if there is a relationship between their MRIs and the MCAS. Both of these vehicles were looked at in an effort to: 1) obtain 3rd MAW maintainer perception of maintenance operations safety, 2) evaluate the ability of the MCAS to detect differences in squadron maintenance safety climate and how it is associated with the MRI histories and 3) determine if human error is a significant factor in 3rd MAW MRIs using HFACS-ME. This research involved the collection of 977 survey results during the first part of Fiscal Year (FY) 2000 and the analysis of 21 MRIs from January 1998 to December 1999.

B. CONCLUSIONS

The results of this study show that the MCAS can be utilized by Naval Aviation as a tool for effectively capturing a maintainer's perceptions of safety in maintenance operations. Principal Component Analysis fails to identify any single MOSE component or question that was responsible for controlling the outcome of the survey. Through analysis of the removed surveys with missing values or the same response to all 43 questions it was determined that question order effects were present. One minor finding was Question 21 was found to not load well in the first principal component due to the negative wording in the question.

Additionally, through Analysis of Variance (ANOVA) and multiple comparison testing, it is determined that the MCAS is able to detect differences between both the squadron's mean MCAS and MOSE component response. Through this analysis, it was discovered that Risk Management is a concern within the 3rd MAW. It also highlighted a positive outlook with respect to the command Process Auditing. Unfortunately, this study was unable to conduct the same analysis at the Marine Air Group or Type Aircraft level due to an insufficient number of surveys across these levels of the 3rd MAW.

Finally, the analysis done on the Maintenance Related Incidences (MRIs) of the 3rd MAW using HFACS-ME was also limited by the number of surveys as well as a general low rate of MRIs. The fact that the safety climate of a squadron lasts about two years makes it impossible to conduct an in-depth analysis of the ordered causal factors relating to the MRIs in a one time study. The low t-value associated with the linear regression fit with squadron F included and removed lead one to conclude that this one study is insufficient to demonstrate a relationship between the two. However, based on

the content analysis of the MRIs and the MCAS MOSE components it is clear that the survey is addressing issues related to incidents of the 3rd MAW. Of note is the low rate of the Reward System and Safety Climate (RS) component in the incidents of the 3rd MAW but this could simply be due to chance with such a relatively low number of incidents.

C. RECOMMENDATIONS

Based on conclusions from the study, a number of recommendations concerning question order, minor MCAS modifications and administration and analysis of the survey are listed below:

1. The 3rd MAW should review their Risk Management maintenance processes. In addition this study can be used as a starting point for year over year comparison of 3rd MAW MCAS and MRI data to determine to what degree there is a relationship between perceptions of maintenance safety and actual safety records

2. Minor modifications of the MCAS need to be made including, 1) Positively wording question 21 2) randomizing the questions with respect to the MOSE components to reduce response order effects and 3) revisiting the questions of the Reward System component to ensure they are adequately addressing casual factors in MRIs.

3. Since often times the survey was given under different circumstances, a more systematic administration of the MCAS needs to be developed. One method currently being developed by the School of Aviation Safety at the Naval Postgraduate School is on-line version of the MCAS similar to the Command Safety Assessment (CSA) currently being given to aircrew. This method has the advantage of real time analysis of surveys from a command.

Implementation of these recommendations would lead to a more effective and useful MCAS for use in the future by other aviation commands. In addition, as previous research has shown intervention in the Risk Management practices of the 3rd MAW could lead to substantial reductions in the MRIs associated with this casual factor.

While the above recommendations will positively affect the MCAS, further research is needed in the following areas:

1. In order to reduce the response error that may be introduced by a persons background it is recommend that a study be undertaken to asses the relationship, if any, between a persons demographic and MCAS responses. To completely validate this survey, it needs to be shown that the MCAS responses are independent of the demographics of the respondent.

2. Finally, to accurately assess the link between the MCAS and MRI rate a systematic study of squadrons and their mishap rate needs to be conducted.

The benefits to this additional research, will be to make the MCAS a more effective tool in capturing maintainer perceptions on maintenance operations while continuing to strive for the ultimate safety goal of intervention by aviation commanders in real time to correct safety deficiencies that will eventually lead to a future incident.

APPENDIX A. 43-ITEM MAINTENACE CLIMATE ASSESSMENT SURVEY

MAINTENANCE CLIMATE ASSESSMENT SURVEY (MCAS)

Purpose: The MCAS was designed to capture maintainer perceptions of maintenance operations as they relate to safety. Your responses help guide Naval Aviation's on-going efforts to reduce aviation related mishaps. Thank you in advance for your participation!

Directions: Do not write on this form. Fill in all of your responses using the computer sheet provided. Fill in each box that corresponds to your response completely using a pencil. This is not a timed event, so answer each question carefully and honestly. Individual responses will not be reported, only compiled results will be provided to each squadron.

Part I- Demographics has six items requesting unit and biographical data. This information will aid in the response analysis. NO attempts will be made to identify individuals.

Part II- Perceptions has 43 questions pertaining to the maintenance operations. Please chose the response to each item that most correctly reflects your honest opinion. Responses are:

A- Strongly Agree B- Agree C- Neutral D- Disagree E- Strongly Disagree

Part I- Demographics

Line 1 Fill in the numbered circle corresponding to your community?

VMGR	(1)	VMA	(2)	VMFA	(3)	HMT	(4)	HMM(5)
VMAQ	(6)	HMH	(7)	VMH	(9)	Other	(9)	( )

Line 2-4 Fill in the circles corresponding to your squadron number

Line 5 Fill in the numbered circle corresponding with you rank
(1) E1-3 (2)E4-5 (3)E6-7 (4)E8-9 (5)WO1-4 (6)O1-03 (7)O4-5

Line 6 Fill in the numbered circle corresponding to your total years of Aviation Maintenance experience
(1) <1 (2) 1-2 (3) 3-5 (4)6-10 (5)11-15 (6)15-20 (7)20+

Line 7 Fill in the numbered circle corresponding to your work center
(1)Powerplants (2)Airframes (3)Survival (4) Quality Assurance
(5)Ordnance (6)Avionics (7)MAINT Control (8)Line (9)Other

Line 8 Fill in the numbered circle corresponding to your shift
(1)Day (2)Night

Part II Perceptions

Fill in the lettered circle that corresponds with your response to each item.

	SA	A	N	D	SD
1. The command adequately reviews and updates safety.	(A)	(B)	(C)	(D)	(E)
2. The command monitors maintainer qualifications and has a program that targets training deficiencies.	(A)	(B)	(C)	(D)	(E)
3. The command uses safety and medical staff to identify/ manage personnel at risk.	(A)	(B)	(C)	(D)	(E)
4. CDIs/QARs routinely monitor maintenance evolutions.	(A)	(B)	(C)	(D)	(E)

	SA	A	N	D	SD
5. Tool control is taken seriously in the command and support equipment licensing is closely monitored.	(A)	(B)	(C)	(D)	(E)
6. Signing off personnel qualifications are taken seriously.	(A)	(B)	(C)	(D)	(E)
7. Our command climate promotes safe maintenance.	(A)	(B)	(C)	(D)	(E)
8. Supervisors discourage SOP, NAMP, or other procedure violations and encourage reporting safety concerns.	(A)	(B)	(C)	(D)	(E)
9. Peer influence discourages SOP, NAMP, or other violations and individuals feel free to report them.	(A)	(B)	(C)	(D)	(E)
10. Violations of SOP, NAMP, or other procedures are not common in this command.	(A)	(B)	(C)	(D)	(E)
11. The command recognizes individual safety achievement through rewards and incentives.	(A)	(B)	(C)	(D)	(E)
12. Personnel are comfortable approaching supervisors about personal problems/illness	(A)	(B)	(C)	(D)	(E)
13. Safety NCO, QAR, and CDI, are sought after billets.	(A)	(B)	(C)	(D)	(E)
14. Unprofessional behavior is not tolerated in the command	(A)	(B)	(C)	(D)	(E)
15. The command has a reputation for quality maintenance and sets standards to maintain quality control.	(A)	(B)	(C)	(D)	(E)
16. QA and Safety are well respected, and are seen as essential to mission accomplishment.	(A)	(B)	(C)	(D)	(E)
17. QARs/CDIs sign-off after required actions are complete and are not pressured by supervisors to sign-off.	(A)	(B)	(C)	(D)	(E)
18. Maintenance on detachments is of the same quality as that at home station.	(A)	(B)	(C)	(D)	(E)
19. Required publications/tools/equipment are available, current/serviceable, and used.	(A)	(B)	(C)	(D)	(E)
20. QARs are helpful, and QA is not "feared" in my unit.	(A)	(B)	(C)	(D)	(E)
21. Multiple job assignments and collateral duties adversely affect maintenance.	(A)	(B)	(C)	(D)	(E)
22. Safety is part of maintenance planning, and additional training/support is provided as needed.	(A)	(B)	(C)	(D)	(E)

		SA	A	N	D	SD
23.	Supervisors recognize unsafe conditions and manage hazards associated with maintenance and the flight-line.	(A)	(B)	(C)	(D)	(E)
24.	I am provided adequate resources, time, personnel to accomplish my job.	(A)	(B)	(C)	(D)	(E)
25.	Personnel turnover does not negatively impact the command's ability to operate safely.	(A)	(B)	(C)	(D)	(E)
26.	Supervisors are more concerned with safe maintenance than the flight schedule, and do no permit cutting corners.	(A)	(B)	(C)	(D)	(E)
27.	Day/Night Check have equal workloads, and staffing is sufficient on each shift.	(A)	(B)	(C)	(D)	(E)
28.	Supervisors shield personnel from outside pressures and are aware of individual workload.	(A)	(B)	(C)	(D)	(E)
29.	Based upon my command's current assets/manning it is not over-committed.	(A)	(B)	(C)	(D)	(E)
30.	My command temporarily restricts maintainers who are having a problems.	(A)	(B)	(C)	(D)	(E)
31.	Safety decisions are made at the proper levels and work center supervisor decisions are respected.	(A)	(B)	(C)	(D)	(E)
32.	Supervisors communicate command safety goals and are actively engaged in the safety program.	(A)	(B)	(C)	(D)	(E)
33.	Supervisors set the example for following to maintenance standards and ensure compliance.	(A)	(B)	(C)	(D)	(E)
34.	In my command safety is a key part of all maintenance operations, and all are responsible/accountable for safety.	(A)	(B)	(C)	(D)	(E)
35.	Safety education and training are comprehensive and effective.	(A)	(B)	(C)	(D)	(E)
36.	All maintenance evolutions are properly briefed, supervised, and staffed by qualified personnel.	(A)	(B)	(C)	(D)	(E)
37.	Maintenance Control is effective in managing all maintenance activities.	(A)	(B)	(C)	(D)	(E)
38.	Good communication exists up/down the chain of command.	(A)	(B)	(C)	(D)	(E)
39.	I get all the information I need to do my job safely.	(A)	(B)	(C)	(D)	(E)
40.	Work center supervisors coordinate their actions.	(A)	(B)	(C)	(D)	(E)
41.	My command has effective pass-down between shifts.	(A)	(B)	(C)	(D)	(E)

		SA	A	N	D	SD
42.	Maintenance Control troubleshoots/resolves gripes before flight.	(A)	(B)	(C)	(D)	(E)
		SA	**A**	**N**	**D**	**SD**
43.	Maintainers are briefed on potential hazards associated with maintenance activities.	(A)	(B)	(C)	(D)	(E)

APPENDIX B. MODEL OF SAFETY EFFECTIVENESS COMPONENTS

COMPONENT 1: PROCESS AUDITING

1. The command adequately reviews and updates safety practices.
2. The command monitors maintainer qualifications and has a program that targets training deficiencies.
3. The command uses safety and medical staff to identify/manage personnel at risk.
4. CDIs/QARs routinely monitor maintenance evolutions.
5. Tool Control is taken seriously in the command and support equipment licensing is closely monitored.
6. Signing personal qualifications are taken seriously.

COMPONENT 2: REWARD SYSTEM and SAFETY CLIMATE

1. Our command climate promotes safe maintenance and flight operations.
2. Supervisors discourage SOP, NAMP or other procedure violations and encourage reporting safety concern.
3. Peer influence discourages SOP, NAMP or other violations and individuals feel free to report them.
4. Violations of SOP, NAMP or other procedures are not common in this command.
5. The command recognizes individual safety achievement through rewards and incentives.
6. Personnel are comfortable approaching supervisors about personal problems/illness.
7. Safety NCO, QAR, and CDI, are sought after billets.
8. Unprofessional behavior is not tolerated in the command.

COMPONENT 3: QUALITY ASSURANCE

1. The command has a reputation for quality maintenance and has set standards to maintain quality control.
2. QA and Safety are well respected, and are seen as essential to mission accomplishment.
3. QARs/CDIs sign-off after required actions are complete and are not pressured by supervisors to sign-off.
4. Maintenance on detachments is the same quality as that at home station.
5. Required publications/tools/equipment are available, current/serviceable, and used.
6. QARs are helpful, and QA is not "feared" in my unit.

COMPONENT 4: RISK MANAGEMENT

1. Multiple job assignments and collateral duties adversely affect maintenance.
2. Safety is part of maintenance planning, and additional training/support is provided as needed.
3. Supervisors recognize unsafe conditions and manage hazards associated with maintenance and the flight line.
4. I am provided adequate resources, time, personnel to accomplish my job.
5. Personnel turnover does not negatively impact the command's ability to operate safely.
6. Supervisors are more concerned with safe maintenance than the flight schedule, and do not permit cutting corners.
7. Day/Night Check have equal workloads, and staffing is sufficient on each shift.
8. Supervisors shield personnel from outside pressures and are aware of individual workload.
9. Based upon my command's current assets/manning it is not over-committed.

COMPONENT 5: COMMAND AND CONTROL

1. My command temporarily restricts maintainers who are having problems.
2. Safety decisions are made at the proper levels, work center supervisors decisions are respected.
3. Supervisors communicate command safety goals and are actively engaged in the safety program.
4. Supervisors set the example for following to maintenance standards and ensure compliance.
5. In my command safety is a key part of all maintenance operations and all are responsible/accountable for safety.
6. Safety education and training are comprehensive and effective.
7. All maintenance evolutions are properly briefed, supervised, and staffed by qualified personnel.
8. Maintenance control is effective in managing all maintenance activities.

COMPONENT 6: COMMUNICATION / FUNCTIONAL RELATIONSHIPS

1. Good communication exists up/down the chain of command.
2. I get all the information I need to do my job safely.
3. Work center supervisors coordinate their actions.
4. My command has effective pass-down between shifts.
5. Maintenance Control troubleshoots/resolves gripes before flight.
6. Maintainers are briefed on potential hazards associated with maintenance activities.

APPENDIX C. 3RD MAW QUESTION AVERAGES BY SQUADRON

Sqdrn	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
A	3.76	3.57	3.43	4.05	3.81	3.86	3.86	3.38	3.29	3.29	2.90	3.81	3.33	3.43	3.76
B	4.43	4.10	3.38	4.33	4.24	3.95	3.95	3.86	3.48	3.33	3.05	3.81	3.19	3.57	4.24
C	4.14	3.86	3.19	4.38	4.33	4.10	4.00	3.43	3.05	3.43	2.48	3.33	3.48	3.52	3.76
D	3.90	3.48	3.24	4.10	3.90	3.62	3.71	3.52	3.57	3.76	3.43	3.71	3.38	3.00	3.90
E	3.75	3.63	3.00	3.88	3.50	3.88	4.13	3.63	3.75	3.25	3.13	4.00	3.38	4.25	4.50
F	4.26	3.90	3.76	4.19	4.14	3.86	3.90	3.71	3.67	3.62	3.29	4.00	3.76	3.38	3.81
G	4.16	3.76	3.14	4.10	3.81	3.76	3.48	3.71	3.43	3.52	2.38	3.33	3.48	3.62	4.05
H	4.42	3.89	3.11	4.26	3.89	3.74	4.05	3.79	3.37	3.68	2.68	3.42	3.05	3.68	4.53
I	4.14	3.90	3.29	4.29	4.24	4.05	4.05	3.48	3.14	3.52	2.62	3.52	3.19	3.57	4.24
J	4.22	3.78	3.11	4.11	4.22	4.33	4.22	4.11	3.56	3.67	3.00	3.67	3.67	4.00	4.44
K	3.73	3.73	3.18	3.45	4.09	3.00	3.27	3.27	2.91	3.00	3.18	3.00	3.18	3.64	2.91
L	4.24	3.76	3.57	4.57	4.10	3.86	3.86	3.90	3.52	3.76	3.05	3.81	4.00	4.05	4.48
M	3.76	3.62	2.76	3.76	4.19	3.57	3.57	3.43	3.10	3.00	2.81	3.38	3.48	3.24	3.71
N	3.44	3.67	3.67	3.89	3.89	3.67	3.78	3.67	3.56	3.56	3.33	3.78	2.78	3.67	3.78
O	3.76	3.62	3.43	3.86	3.38	3.43	3.38	3.43	3.29	3.05	2.76	3.24	3.05	3.52	3.62
P	3.84	3.62	3.62	4.05	3.67	3.67	3.76	3.19	2.95	3.52	2.38	3.71	3.24	3.48	3.95
Q	4.13	3.63	3.75	4.50	3.63	4.13	4.13	4.50	3.88	3.63	3.25	4.00	3.25	4.38	3.63
AVG	**4.01**	**3.74**	**3.33**	**4.10**	**3.94**	**3.79**	**3.83**	**3.65**	**3.38**	**3.45**	**2.92**	**3.62**	**3.35**	**3.65**	**3.96**

Sqdrn	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30
A	3.52	3.81	3.71	3.38	3.62	3.62	3.29	3.81	2.62	3.33	2.95	2.05	3.33	3.10	2.90
B	4.29	4.19	3.57	3.43	3.95	3.43	3.86	4.19	3.38	3.52	3.90	1.71	3.76	3.43	2.90
C	3.67	3.52	3.52	3.29	3.62	3.86	3.81	4.05	2.95	3.05	3.48	2.14	3.19	3.14	2.62
D	3.76	3.57	3.62	3.33	3.76	3.76	3.86	3.81	2.81	3.43	3.38	2.86	3.14	2.95	3.19
E	3.88	3.75	2.88	3.63	3.75	3.63	3.63	4.13	3.25	2.88	3.63	2.50	3.38	2.88	3.13
F	3.48	3.43	3.33	3.86	3.71	3.71	4.05	3.81	3.67	3.90	3.71	3.10	3.43	3.43	3.43
G	3.67	3.38	3.24	3.05	3.14	3.33	3.29	3.76	2.38	3.00	2.76	2.57	3.00	2.76	3.14
H	3.95	3.74	3.63	3.05	3.47	3.47	4.05	4.05	3.68	3.21	3.95	3.00	3.53	3.58	3.26
I	3.48	3.67	3.48	3.52	2.76	3.43	3.57	4.24	3.29	2.81	3.19	2.86	3.14	2.95	2.62
J	3.67	4.00	3.89	3.78	3.56	4.00	4.00	4.00	3.00	3.89	3.33	3.78	3.56	3.11	2.89
K	3.27	3.36	3.64	3.91	3.09	4.00	3.91	3.64	3.09	3.36	2.73	2.09	2.73	2.64	3.09
L	4.10	3.90	4.05	3.52	3.90	3.52	3.90	4.05	3.52	3.48	3.62	3.38	3.52	3.05	3.57
M	3.67	3.05	3.00	3.29	3.52	3.76	3.24	3.62	2.52	2.90	2.86	2.24	2.86	2.90	2.86
N	3.22	3.78	3.67	3.33	3.78	3.56	3.33	3.89	2.89	3.00	3.00	2.56	3.78	2.56	3.22
O	3.71	3.00	3.52	2.81	3.24	3.38	3.10	3.62	2.52	2.71	2.76	2.10	2.81	2.38	3.29
P	3.57	3.19	3.95	3.52	3.76	3.57	3.86	3.67	2.90	3.14	2.86	2.95	3.00	2.81	3.05
Q	3.50	4.25	3.88	4.13	3.88	2.88	4.00	4.38	3.63	3.50	3.75	3.75	4.13	3.50	3.25
AVG	**3.67**	**3.62**	**3.56**	**3.46**	**3.56**	**3.58**	**3.69**	**3.92**	**3.07**	**3.24**	**3.29**	**2.68**	**3.31**	**3.01**	**3.08**

Sqdrn	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40	Q41	Q42	Q43
A	3.76	3.71	3.67	3.81	3.57	3.14	3.43	2.57	3.71	3.33	3.71	3.67	3.57
B	4.29	3.95	4.24	4.10	4.05	3.67	3.62	3.24	3.86	3.67	3.95	3.62	3.62
C	3.81	3.76	3.43	4.05	3.76	3.14	2.67	2.95	3.62	3.57	3.81	3.00	3.24
D	3.57	3.62	3.57	3.67	3.81	3.33	3.14	3.38	3.52	3.52	3.57	3.24	3.67
E	3.75	3.63	3.88	3.75	4.00	3.13	3.50	3.13	3.63	3.63	3.38	3.50	3.88
F	3.48	3.67	3.71	4.00	3.90	3.76	3.48	3.52	3.81	3.67	3.33	3.29	3.67
G	3.52	3.43	3.43	3.71	3.43	2.95	3.00	2.43	3.24	3.62	3.71	3.05	3.19
H	4.00	3.79	3.79	4.00	3.79	3.53	3.53	3.58	3.89	3.58	3.47	3.84	3.89
I	3.33	3.71	3.90	3.71	3.90	3.38	3.48	3.10	3.67	3.52	3.86	3.29	3.76
J	4.00	4.11	4.11	4.11	4.00	3.89	4.22	3.89	3.89	3.89	4.11	3.56	3.89
K	2.91	3.27	3.36	3.73	4.00	3.45	2.73	2.82	3.45	3.00	3.09	3.18	3.45
L	4.05	4.14	4.05	4.00	3.57	3.86	3.43	3.81	3.95	4.10	3.95	3.90	3.81
M	3.52	3.29	3.33	3.52	3.14	3.00	2.67	2.62	3.48	3.33	2.90	3.29	3.52
N	3.44	3.67	3.78	3.56	3.33	3.22	3.33	3.11	3.33	3.56	3.67	3.44	3.56
O	3.48	3.48	3.52	3.38	3.19	2.81	2.29	2.48	3.33	3.48	3.38	3.10	3.43
P	3.62	3.52	3.48	3.81	3.71	3.48	2.90	3.00	3.95	3.81	3.95	3.43	3.62
Q	3.75	3.88	3.88	4.13	3.88	3.88	3.75	3.50	3.75	4.13	3.88	3.50	3.75
AVG	**3.66**	**3.68**	**3.71**	**3.83**	**3.71**	**3.39**	**3.24**	**3.12**	**3.65**	**3.61**	**3.63**	**3.40**	**3.62**

APPENDIX D. 3RD MAW MAG & TYPE AIRCRAFT MOSE COMPONENTS

MAGS	Process Auditing	Reward System	Quality Assurance	Risk Manage	Command & Control	Comms/ Func Rel	MAG Mean
W	3.79	3.58	3.70	3.45	3.63	3.57	**3.62**
X	3.87	3.55	3.65	3.46	3.62	3.58	**3.62**
Y	3.78	3.50	3.65	3.24	3.48	3.52	**3.53**
Z	3.82	3.36	3.59	3.15	3.45	3.41	**3.46**
Component Mean	**3.82**	**3.50**	**3.65**	**3.33**	**3.55**	**3.52**	**3.55**

Type Aircraft	Process Auditing	Reward System	Quality Assurance	Risk Manage	Command & Control	Comms/ Func Rel	Type Mean
VMFA	3.83	3.69	3.77	3.53	3.64	3.62	**3.68**
VMFAT	3.53	3.18	3.36	3.13	3.32	3.17	**3.28**
VMGR	3.96	3.74	3.89	3.63	3.92	3.87	**3.83**
VMA	3.87	3.55	3.65	3.46	3.62	3.58	**3.62**
HMH	3.81	3.50	3.68	3.28	3.50	3.56	**3.55**
HMM	3.68	3.38	3.51	3.04	3.37	3.36	**3.39**
HMLA	3.84	3.33	3.55	3.16	3.39	3.40	**3.45**
HMT	4.07	3.53	3.94	3.47	3.85	3.66	**3.75**
Component Mean	**3.83**	**3.49**	**3.67**	**3.34**	**3.58**	**3.53**	**3.55**

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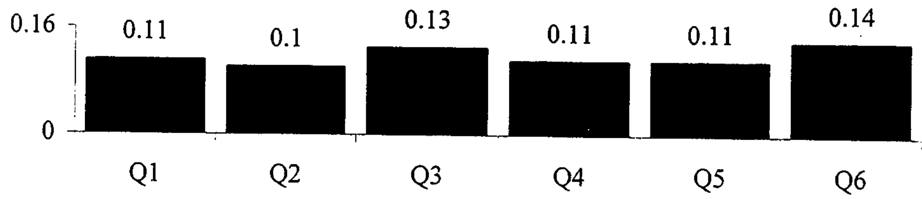
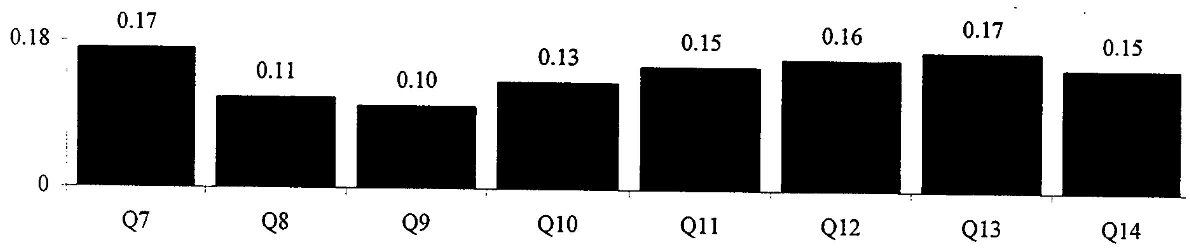
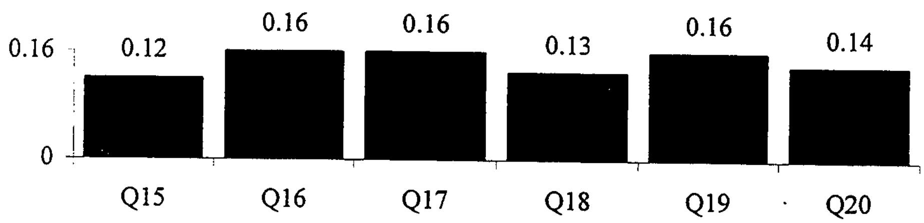
APPENDIX E. 3RD MAW COMPONENT ONE LOADINGS



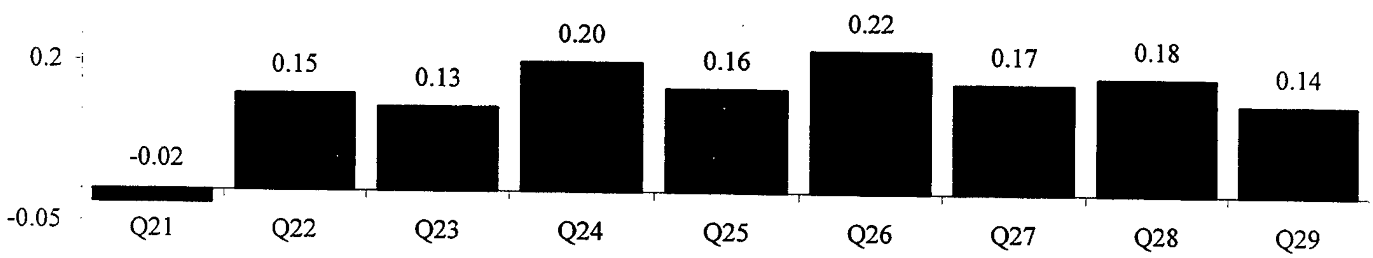
Process Auditing Loadings Component 1



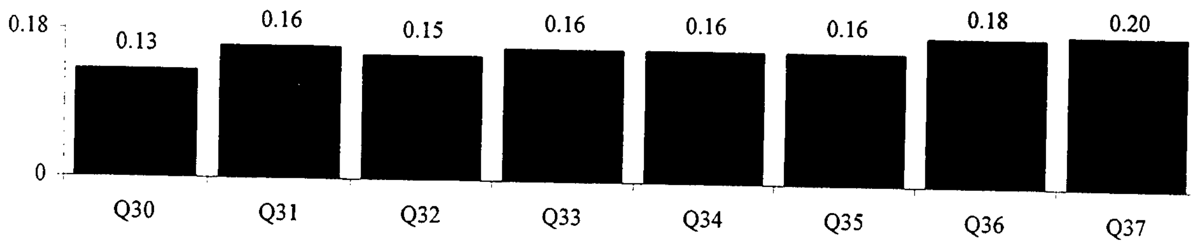
Reward System Loadings Component 1



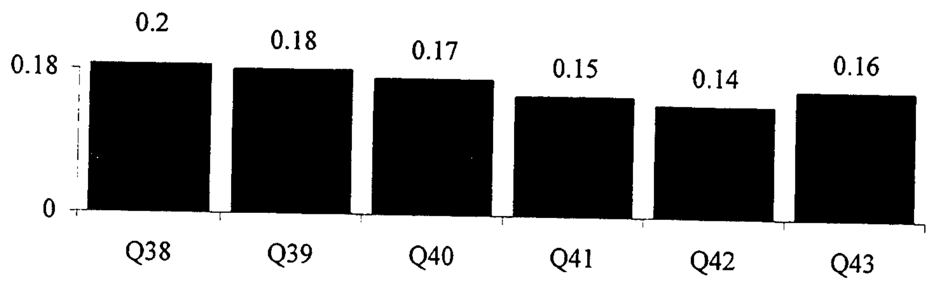
Quality Assurance Loadings Component 1



Risk Management Loadings Component 1



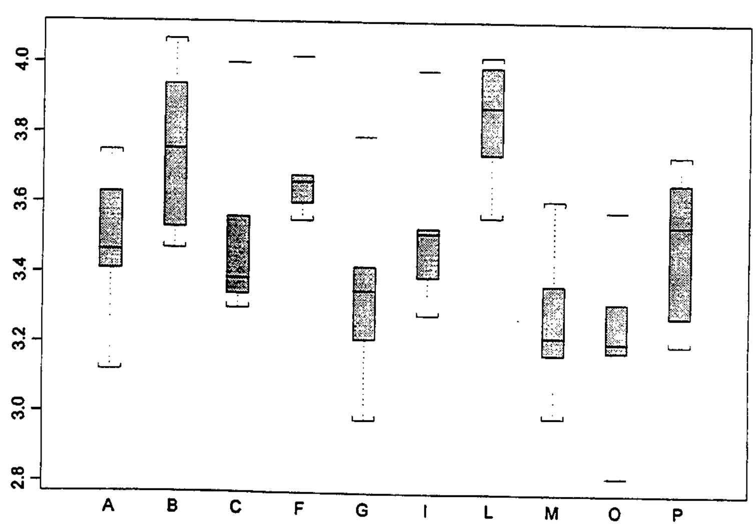
Command and Control Loadings Component 1



Risk Management Loadings Component 1

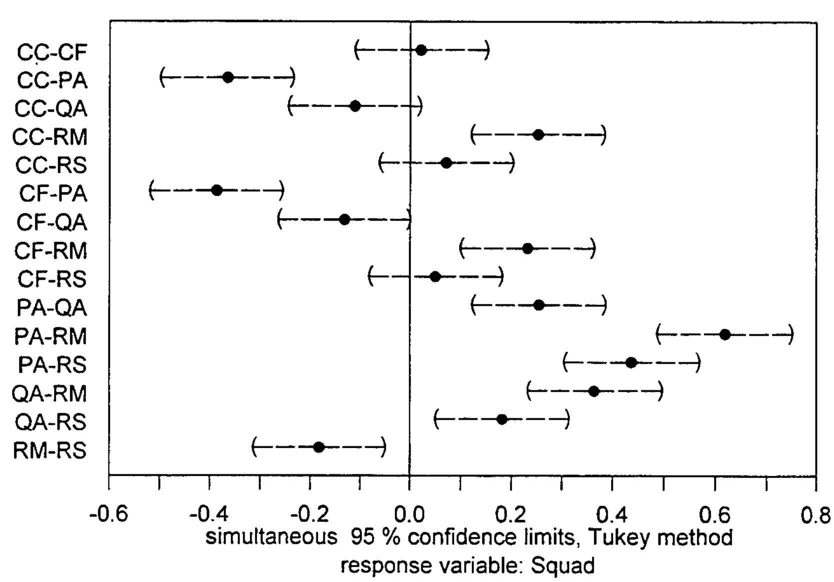
APPENDIX F. SPLUS CODE & OUTPUT FOR MCAS ANOVA & MANOVA

```
> tm
    PA   RS   QA   RM   CC   CF
A 3.75 3.41 3.63 3.12 3.50 3.43
B 4.07 3.53 3.94 3.47 3.85 3.66
C 4.00 3.34 3.56 3.30 3.40 3.37
F 4.02 3.67 3.60 3.65 3.68 3.55
G 3.79 3.37 3.42 2.98 3.33 3.21
I 3.98 3.39 3.52 3.28 3.51 3.53
L 4.02 3.74 3.99 3.56 3.83 3.92
M 3.61 3.25 3.37 2.99 3.17 3.19
O 3.58 3.21 3.32 2.82 3.18 3.20
P 3.74 3.28 3.66 3.20 3.45 3.63

> tm1_data.frame(Avg = unlist(c(tm)), Squad = dimnames(tm)
[[1]][row(tm)], Comp = dimnames(tm)[[2]][col(tm)])

>> tmaov_anova(aov(Avg ~ Squad + Comp, data = tm1))
> tmaov
Analysis of Variance Table

Response: Avg

Terms added sequentially (first to last)
          Df Sum of Sq Mean Sq F Value     Pr(F)
    Squad  9      2.27   0.252    26.7 3.22e-015
     Comp  5      2.13   0.426    45.1 2.20e-016
Residuals 45      0.43   0.009

> tapply(tm1[,"Avg"],tm1[,"Comp"],mean)
   CC   CF   PA  QA   RM   RS
 3.49 3.47 3.86 3.6 3.24 3.42

> boxplot(split(tm1[,"Avg"],tm1[,"Squad"]))
```



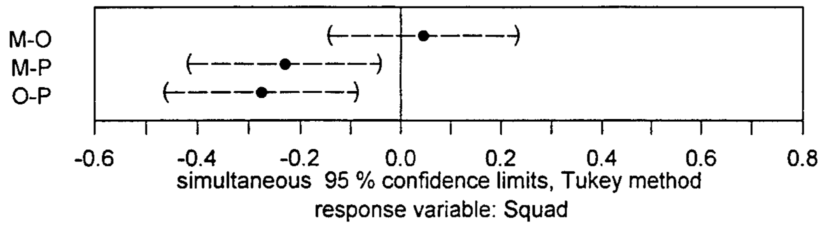
```
> aov1_anova(aov(Avg ~ Squad + Comp, data = tm1))
> aov2_aov(Avg ~ Squad + Comp, data = tm1)

> mult1_multicomp(aov2, focus = "Comp", method="tukey",plot=T)

> mult1

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

critical point: 2.976
response variable: Squad

intervals excluding 0 are flagged by '****'
```

	Estimate	Std.Error	Lower Bound	Upper Bound	
CC-CF	0.021	0.0435	-0.1080	0.15000	
CC-PA	-0.366	0.0435	-0.4950	-0.23700	****
CC-QA	-0.111	0.0435	-0.2400	0.01840	
CC-RM	0.253	0.0435	0.1240	0.38200	****
CC-RS	0.071	0.0435	-0.0584	0.20000	
CF-PA	-0.387	0.0435	-0.5160	-0.25800	****
CF-QA	-0.132	0.0435	-0.2610	-0.00264	****
CF-RM	0.232	0.0435	0.1030	0.36100	****
CF-RS	0.050	0.0435	-0.0794	0.17900	
PA-QA	0.255	0.0435	0.1260	0.38400	****
PA-RM	0.619	0.0435	0.4900	0.74800	****
PA-RS	0.437	0.0435	0.3080	0.56600	****
QA-RM	0.364	0.0435	0.2350	0.49300	****
QA-RS	0.182	0.0435	0.0526	0.31100	****
RM-RS	-0.182	0.0435	-0.3110	-0.05260	****



```
> mult2_multicomp(aov2, focus = "Squad", method="tukey",plot=T)
WARNING: Point out of bounds: x = -0.680036, y = 11.000000

> mult2

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

critical point: 3.3269
response variable: Squad

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
A-B -0.28000    0.0561     -0.4670     -0.0933 ****
A-C -0.02170    0.0561     -0.2080      0.1650
A-F -0.22200    0.0561     -0.4080     -0.0350 ****
A-G  0.12300    0.0561     -0.0634      0.3100
A-I -0.06170    0.0561     -0.2480      0.1250
A-L -0.37000    0.0561     -0.5570     -0.1830 ****
A-M  0.21000    0.0561      0.0233      0.3970 ****
A-O  0.25500    0.0561      0.0683      0.4420 ****
A-P -0.02000    0.0561     -0.2070      0.1670
B-C  0.25800    0.0561      0.0716      0.4450 ****
B-F  0.05830    0.0561     -0.1280      0.2450
B-G  0.40300    0.0561      0.2170      0.5900 ****
B-I  0.21800    0.0561      0.0316      0.4050 ****
B-L -0.09000    0.0561     -0.2770      0.0967
B-M  0.49000    0.0561      0.3030      0.6770 ****
B-O  0.53500    0.0561      0.3480      0.7220 ****
B-P  0.26000    0.0561      0.0733      0.4470 ****
C-F -0.20000    0.0561     -0.3870     -0.0133 ****
C-G  0.14500    0.0561     -0.0417      0.3320
C-I -0.04000    0.0561     -0.2270      0.1470
C-L -0.34800    0.0561     -0.5350     -0.1620 ****
C-M  0.23200    0.0561      0.0450      0.4180 ****
C-O  0.27700    0.0561      0.0900      0.4630 ****
C-P  0.00167    0.0561     -0.1850      0.1880
F-G  0.34500    0.0561      0.1580      0.5320 ****
F-I  0.16000    0.0561     -0.0267      0.3470
F-L -0.14800    0.0561     -0.3350      0.0384
F-M  0.43200    0.0561      0.2450      0.6180 ****
F-O  0.47700    0.0561      0.2900      0.6630 ****
F-P  0.20200    0.0561      0.0150      0.3880 ****
G-I -0.18500    0.0561     -0.3720      0.0017
G-L -0.49300    0.0561     -0.6800     -0.3070 ****
G-M  0.08670    0.0561     -0.1000      0.2730
G-O  0.13200    0.0561     -0.0550      0.3180
G-P -0.14300    0.0561     -0.3300      0.0434
I-L -0.30800    0.0561     -0.4950     -0.1220 ****
I-M  0.27200    0.0561      0.0850      0.4580 ****
I-O  0.31700    0.0561      0.1300      0.5030 ****
I-P  0.04170    0.0561     -0.1450      0.2280
L-M  0.58000    0.0561      0.3930      0.7670 ****
L-O  0.62500    0.0561      0.4380      0.8120 ****
L-P  0.35000    0.0561      0.1630      0.5370 ****
M-O  0.04500    0.0561     -0.1420      0.2320
```

```
M-P -0.23000    0.0561     -0.4170     -0.0433 ****
O-P -0.27500    0.0561     -0.4620     -0.0883 ****
```




```
> aov1
Analysis of Variance Table

Response: Avg

Terms added sequentially (first to last)
          Df Sum of Sq Mean Sq F Value     Pr(F)
    Squad  9      2.27   0.252    26.7 3.22e-015
     Comp  5      2.13   0.426    45.1 2.20e-016
Residuals 45      0.43   0.009
> aov2
Call:
   aov(formula = Avg ~ Squad + Comp, data = tm1)

Terms:
                Squad Comp Residuals
 Sum of Squares  2.27 2.13      0.43
Deg. of Freedom     9    5        45

Residual standard error: 0.0972
Estimated effects are balanced

> summary(aov1)
         Df          Sum of Sq        Mean Sq          F Value
Pr(F)
    Min.: 5.0      Min.:0.425      Min.:0.00945      Min.:26.7
Min.:2.22e-016
 1st Qu.: 7.0   1st Qu.:1.280   1st Qu.:0.13100   1st Qu.:31.3   1st
Qu.:9.71e-016
  Median: 9.0    Median:2.130    Median:0.25200    Median:35.9
Median:1.72e-015
    Mean:19.7      Mean:1.610      Mean:0.22900      Mean:35.9
Mean:1.72e-015
 3rd Qu.:27.0   3rd Qu.:2.200   3rd Qu.:0.33900   3rd Qu.:40.5   3rd
Qu.:2.47e-015
    Max.:45.0      Max.:2.270      Max.:0.42600      Max.:45.1
Max.:3.22e-015
                                                     NA's: 1.0
NA's:1.00e+000
```

```
> summary(aov2)
          Df Sum of Sq Mean Sq F Value     Pr(F)
    Squad  9      2.27   0.252    26.7 3.22e-015
     Comp  5      2.13   0.426    45.1 2.20e-016
Residuals 45      0.43   0.009
> summary(anova(aov2))
        Df            Sum of Sq          Mean Sq              F Value
Pr(F)
    Min.: 5.0       Min.:0.425       Min.:0.00945       Min.:26.7
Min.:2.22e-016
 1st Qu.: 7.0    1st Qu.:1.280    1st Qu.:0.13100    1st Qu.:31.3    1st
Qu.:9.71e-016
  Median: 9.0     Median:2.130     Median:0.25200     Median:35.9
Median:1.72e-015
    Mean:19.7       Mean:1.610       Mean:0.22900       Mean:35.9
Mean:1.72e-015
 3rd Qu.:27.0    3rd Qu.:2.200    3rd Qu.:0.33900    3rd Qu.:40.5    3rd
Qu.:2.47e-015
    Max.:45.0       Max.:2.270       Max.:0.42600       Max.:45.1
Max.:3.22e-015
                                                        NA's: 1.0
NA's:1.00e+000
```

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APPENDIX G. 3RD MAW REGRESSION DATA

```
Data set = maw, Name of Fit = L1
Normal Regression
Kernel mean function = Identity
Response      = Incidents
Terms         = (Mean MCAS)
Coefficient Estimates
Label        Estimate        Std. Error    t-value
Constant    -94.6783         171.398        -0.552
Mean MCAS    32.7781         48.7714         0.672

R Squared:                0.0534434
Sigma hat:                 29.822
Number of cases:               10
Degrees of freedom:             8

Summary Analysis of Variance Table
Source          df      SS             MS           F      p-value
Regression       1    401.709       401.709       0.45     0.5205
Residual         8    7114.82       889.352
 Lack of fit     7    6993.14       999.019       8.21     0.2626
 Pure Error      1     121.68        121.68

Data set = mawminusF, Name of Fit = L1
Normal Regression
Kernel mean function = Identity
Response      = Incidents
Terms         = (Mean MCAS)
Coefficient Estimates
Label        Estimate        Std. Error    t-value
Constant     42.3433         77.0016         0.550
Mean MCAS   -8.71304         22.0366        -0.395

R Squared:                0.0218454
Sigma hat:                 12.8019
Number of cases:                9
Degrees of freedom:             7

Summary Analysis of Variance Table
Source          df      SS             MS           F      p-value
Regression       1    25.6212       25.6212       0.16     0.7043
Residual         7    1147.22       163.889
 Lack of fit     6    1025.54       170.924       1.40     0.5688
 Pure Error      1     121.68        121.68
```

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